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Implementation and Administration of Air Quality Transportation Controls An Analysis of the Denver, Colorado Area

Cambridge Systematics, Inc, MA

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IMPLEMENTATION AND ADMINISTRATION OF AIR QUALITY TRANSPORTATION CONTROLS:

An Analysis of the Denver, Colorado Area

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16. Abstract

Using the Denver Air Quality Control Region as a case example, this study examines the costs and benefits associated with the implementation and administration of transportation air quality measures required under the Clean Air Act. The study was undertaken in response to the problems encountered by a number of metropolitan areas in their efforts to implement EPA Transportation Control Plans (TCP's). Program measures examined are vehicle inspection and maintenance, ride sharing, preferential treatment for high occupancy vehicles, parking management, bicycling, and transit. Impacts are described on legal and institutional considerations, urban economics, public administration, zoning, land management, travel behavior and conditions, motor vehicle regulation, capital enforcement costs, air quality, energy and safety. Emphasis is placed on the particular groups or institutions affected and on determination of relative importance of various costs and benefits associated with implementation. The report concludes with an assessment of the implications for federal transportation policy. Analysis methodologies are described in a series of technical appendices. A separate Executive Summary is provided.

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In performing this analysis of both the implementation experience and the potential effectiveness of transportation air quality measures, emphasis has been placed on a variety of institutional issues as well as on more technical considerations such as transportation modal shares and pollutant emissions. We are very grateful to the many persons who provided information necessary to perform these analyses and who helped us to understand both the history of air quality transportation controls in the Denver region and the inter-workings of the several agencies, departments and offices having transportation planning and implementation responsibilities. Identified in Appendix A of the report, these persons have made an immeasurable contribution for which we are deeply appreciative. Not specifically identified in the appendix are the several individuals within the Washington offices of the Department of Transportation and the Environmental Protection Agency who participated in both the conduct and the monitoring of the analyses. They also made invaluable inputs.

We have been impressed by the broad range of disciplinary skills required to effectively design and implement air quality transportation measures. To achieve these requirements, several individuals associated with Cambridge Systematics, as either a member of the staff or as a consultant, have made important contributions to this report. John H. Suhrbier served as Principal Investigator, responsible for the overall conduct of the research and preparation of this report. In addition, he was responsible for the chapter on employer-based ride sharing and collaborated with Frederick A. Wagner on the investigation of preferential treatment facilities for high

occupancy vehicles. Elizabeth A. Deakin served as co-Project Director with particular responsibilities in the areas of transit, land use, and federal policy implications. Other program measure chapters were prepared by Lance A. Neumann, vehicle inspection and maintenance, and by Ann B. Rappaport, parking management and bicycling. The assessment of direct and indirect impacts constituted a critical study component as well. Terry J Atherton was responsible for the travel demand, energy and vehicle emissions analyses. Wendy P. Stern, working with Ms. Deakin, investigated administrative and institutional issues associated with the implementation of air quality transportation measures. Greig Harvey prepared the air quality analysis, examining existing conditions, potential health impacts and possible improvements. Examination of economic impacts was the responsibility of Clifford R. Kern, with major assistance provided by Steven R. Lerman, Gregory K. Ingram, Paul O. Roberts and Ellyn S. Eder.

TABLE OF CONTENTS

Page

CHAPTER 1: INTRODUCTION 1-1

PROJECT OBJECTIVES AND BACKGROUND 1-1

TRANSPORTATION/AIR QUALITY PLANNING 1-4

  Experience Under the 1970 Amendments 1-4
  The Clean Air Act Amendments of 1977 1-10

THE DENVER CONTEXT 1-14

  Urban Area Characteristics 1-14
  The Denver Transportation Control Plan 1-25
  Related Planning and Programming Activities 1-32

ANALYSIS FRAMEWORK 1-38

  Overview 1-38
  Local Involvement 1-42
  Impacts 1-42
  Travel Demand Behavior 1-45

CHAPTER 2: INSTITUTIONAL RESPONSIBILITIES 2-1

INTRODUCTION 2-1

DETERMINANTS OF AGENCY RESPONSIVENESS 2-2

INSTITUTIONAL SETTING 2-7

  Colorado Department of Health 2-8
  Denver Regional Council of Governments 2-16
  Regional Transportation District 2-22
  The City and County of Denver 2-26
  Colorado Department of Highways 2-31
  Summary of Agency Involvement in TCP Implementation 2-32

THE ROLE OF PRIVATE INTEREST GROUPS AND PUBLIC ACCEPTABILITY 2-35

SUMMARY OF FINDINGS 2-42

CHAPTER 3: THE AIR QUALITY PROBLEM IN DENVER 3-1

OVERVIEW 3-1

DENVER'S AIR QUALITY 3-3

  Physical Factors 3-3
  Air Quality Monitoring and Analysis 3-8
  Carbon Monoxide 3-11
  Ozone (Photochemical Oxidant) 3-20
  Nitrogen Dioxide 3-24
  Total Suspended Particulates 3-24

SUMMARY 3-31

Page

CHAPTER 4: VEHICLE EMISSION CONTROLS 4-1

INTRODUCTION 4-1

- Federal Motor Vehicle Emission Control Program 4-1
- Vehicle Emission Control Measures in the TCP 4-4

IMPLEMENTATION OF VEHICLE EMISSIONS CONTROLS 4-6

- Legislative History 4-7
- Agency Involvement and Responsibility 4-13

INSPECTION AND MAINTENANCE PROGRAM DESIGN 4-19

- Vehicles Covered 4-19
- Inspection Frequency 4-20
- Inspection Stations and Inspectors 4-21
- Test Type and Equipment 4-24
- Test Standards/Rejection Rate 4-26
- Inspection Procedure 4-27
- Fees and Penalties 4-28
- Funding 4-28
- Enforcement 4-29
- Mechanic Training and Maintenance 4-30
- Consumer and Hardship Protection 4-32

EFFECTIVENESS AND IMPACTS OF I/M 4-33

- Effectiveness 4-33
- Cost of Maintenance 4-42
- Implementation, Administrative, and Operating Costs 4-42
- Fuel Economy 4-47

SUMMARY OF FINDINGS 4-48

CHAPTER 5: EMPLOYER-BASED RIDE SHARING 5-1

CARPOOLING VS. RIDE SHARING 5-1

THE LEGAL BASIS FOR DENVER RIDE SHARING - APCC REGULATION NO. 9 5-4

THE INSTITUTIONAL RESPONSE TO RIDE SHARING - ASSIGNED AND ASSUMED RESPONSIBILITIES 5-7

- Colorado Department of Health, Air Pollution Control Division 5-7
- Denver Regional Council of Governments 5-15
- Denver Regional Transportation District 5-22
- City and County of Denver 5-25
- Private Employers, Downtown Denver, Inc. 5-26
- Vanpooling 5-29

SUMMARY OF COMMUTER, EMPLOYER, AND AREAWIDE IMPACTS 5-35

SUMMARY OF FINDINGS 5-45

Page

CHAPTER 6: PREFERENTIAL TREATMENT FOR HIGH OCCUPANCY VEHICLES 6-1

PREFERENTIAL TRAFFIC CONTROL 6-1

EVOLUTION OF DENVER'S PREFERENTIAL TREATMENT CONCEPTS 6-5

PLANNING AND IMPLEMENTATION OF PREFERENTIAL TREATMENT FACILITIES 6-8

- The RTD Feasibility Study 6-9
- 16th and 17th Street Bus Lanes 6-12
- Broadway-Lincoln Bus Lanes 6-15
- Lawrence-Larimer Carpool Lanes 6-20
- I-70/US 6 Preferential Treatment Feasibility 6-21
- Ongoing Preferential Treatment Planning Activities 6-24

SUMMARY OF PROJECT IMPACTS 6-28

- Implementation Cost 6-28
- Transit Ridership 6-29
- Bus Travel Times 6-32
- Automobile Travel Times 6-34
- Safety 6-35
- Traffic Diversion 6-36
- Violations and Enforcement 6-38
- Vehicle Miles of Travel, Energy and Emissions 6-40

SUMMARY OF FINDINGS 6-44

CHAPTER 7: PARKING MANAGEMENT 7-1

PARKING MANAGEMENT AND THE DENVER TCP 7-1

PARKING CHARACTERISTICS IN THE DENVER CBD 7-7

- Allocation of Responsibility 7-7
- Parking Supply Overview 7-10
- Department of Public Works Parking 7-12
- Urban Renewal Authority Parking 7-15
- Privately-Owned Public Parking 7-18
- Privately-Owned Private Parking 7-19
- Parking Utilization 7-20

TRANSIT PARK AND RIDE 7-27

VMT REDUCTION 7-30

SUMMARY OF FINDINGS 7-34

CHAPTER 8: BICYCLING 8-1

BACKGROUND 8-1

THE DENVER BIKEWAY PLAN 8-3

- Bikeway Routes 8-3
- Bikeway Maintenance 8-6
- Parking Facilities 8-8
- Registration and Safety 8-8

INSTITUTIONAL RESPONSIBILITIES 8-10

Page

- Implementation of the Denver Bikeway Plan 8-10
  - Denver Planning Office 8-12
  - Department of Public Works 8-12
  - Department of Parks and Recreation 8-13
  - Regional Police Safety Organization 8-13
  - Mountain Bicyclists Corporation 8-14
  - Denver Regional Council of Governments 8-15
  - Colorado Department of Highways 8-16
  - Regional Transportation District 8-17
- ANALYSIS OF PROGRAM IMPACTS 8-18
  - Costs and Funding 8-18
  - System Use 8-21
  - Safety 8-25
  - Travel Time 8-26
  - User Cost 8-28
  - VMT Analysis 8-28
  - Health Effects 8-30
  - Cost/Benefit 8-31
- SUMMARY OF FINDINGS 8-33

CHAPTER 9: TRANSIT IMPROVEMENTS 9-1

- TRANSIT IMPROVEMENTS AND THE DENVER TCP 9-1
- REVIEW OF DENVER TRANSIT IN THE 1960's AND 1970's 9-3
- BUS SYSTEM IMPROVEMENTS 9-10
- OTHER TRANSIT ACTIVITIES 9-15
  - Downtown Shuttle 9-15
  - 16th Street Mall 9-15
  - Corridor Studies 9-17
- TRANSIT CONTRIBUTIONS TO AIR QUALITY IMPROVEMENTS 9-20
- SUMMARY OF FINDINGS 9-25

CHAPTER 10: ECONOMIC IMPACTS 10-1

- INTERRELATION OF TRANSPORTATION AND SPATIAL ACTIVITY PATTERNS 10-1
- POPULATION AND EMPLOYMENT PROJECTIONS 10-5
  - Population Forecasts 10-5
  - Employment Forecasts 10-12
  - Spatial Structure 10-15
- RETAIL SALES IN DOWNTOWN DENVER 10-19
  - Sales Trends 10-21
  - Merchant Perceptions 10-26

Page

IMPACTS ON RETAIL SALES 10-29

Empirical Evidence 10-29
Aggregate Retail Sales Model 10-34
Disaggregate Model of Retail Sales 10-39

THE OFFICE ECONOMY IN DOWNTOWN DENVER 10-44

SUMMARY OF FINDINGS 10-51

CHAPTER 11: EFFECTIVENESS OF AIR QUALITY TRANSPORTATION MEASURES 11-1

INTRODUCTION 11-1

INTERRELATION OF WORK TRIPS, NON-WORK TRAVEL, AND AUTOMOBILE OWNERSHIP 11-3

PROGRAM PACKAGES 11-10

PROJECTED 1985 CONDITIONS 11-16

AIR QUALITY IMPLICATIONS 11-24

SUMMARY OF FINDINGS 11-27

CHAPTER 12: IMPLICATIONS FOR AIR QUALITY/TRANSPORTATION PLANNING 12-1

TRANSFERABILITY OF PROGRAM MEASURE FINDINGS 12-1

OVERALL FINDINGS 12-3

IMPLICATIONS FOR FEDERAL TRANSPORTATION/AIR QUALITY POLICY 12-8

APPENDICES:

A : PERSONS AND AGENCIES INTERVIEWED

B : REGULATION NO. 9, COLORADO AIR POLLUTION CONTROL COMMISSION

C : TRAVEL DEMAND ANALYSIS METHODOLOGY

D : AIR QUALITY ANALYSIS METHODOLOGY

E : INDIRECT ECONOMIC ANALYSIS METHODOLOGY

F : METHODS OF CORRECTION FOR ANNEXATIONS

G : DESCRIPTION AND ASSESSMENT OF DENVER REGIONAL AIR QUALITY MODEL

H : URBAN AIR POLLUTION AND HEALTH EFFECTS

LIST OF FIGURES

FIGURE		PAGE
1-1	Denver and Surrounding Counties	1-15
1-2	Population of the United States and the Four County Denver Region	1-17
1-3	Recent Population Trends in the Denver Region	1-18
1-4	Proportion of All Families in the Lower 40 Percent of the Regional Income Distribution	1-20
1-5	Employment Trends, County Region, 1960-1970	1-21
1-6	Employment Trends Four County Region, 1970-1975	1-22
1-7	CO (Central Area) and HC Emissions by Vehicle Class and Model Year Groupings Independent of TCP Implementation	1-33
1-8	Transportation Control Plans	1-39
1-9	Method of Approach: Cost Effectiveness Analysis	1-41
2-1	Colorado Department of Health - Organization Chart	2-10
2-2	Staff Organization - Denver Regional Council of Governements	2-17
2-3	City and County of Denver Government	2-27
3-1	Primary Topographic Features Affecting Air Quality in Metropolitan Denver	3-4
3-2	Typical Early Morning Downslope Wind in Denver	3-5
3-3	Typical Midday Upslope Wind in Denver	3-6
3-4	Location of Air Quality Monitoring Stations	3-10
3-5	Perimeter of the Violation Area for the 1 Hour CO Standard	3-17
3-6	Second Highest One-Hour CO Concentration: Perimeter of Area Having 12 ppm or Greater	3-18
3-7	Violation of the CO 8-Hour Standard: Perimeter of the Violation Area	3-19
3-8	Perimeter of the Violation Area for the One-Hour Oxidant Standard	3-22
3-9	One-Hour Oxidant Concentration: Perimeter of the Area Exceeding .09 ppm	3-23
3-10	Perimeter of Violation Area for NO_2 Standard	3-26
3-11	Particulate Monitoring Sites	3-27
3-12	Perimeter of Area Having more than 140 $\mu g/m^3$ Annual Average Particulate Concentration (Applicable Standard is 45 $\mu g/m^3$	3-30
4-1	Emission Deterioration Rates	4-35
4-2	Deterioration Rates with Annual I/M	4-37
4-3	Cost Effectiveness Versus Rejection Rate	4-40
5-1	Work Trip VMT Reduction Potential of Ride Sharing Strategies	5-42
6-1	Preferential Treatment for High Occupancy Vehicles in the Denver Metropolitan Area	6-11
6-2	Exclusive Bus Lane Options within the Denver CBD	6-13
6-3	Exclusive Bus Lane Options: Broadway-Lincoln Corridor	6-16

LIST OF FIGURES continued

FIGURE		PAGE
6-4	Freeway off Ramp: Bus Congestion Bypass	6-26
6-5	Freeway on Ramp: Bus Congestion Bypass	6-26
7-1	Existing Zonal Parking Requirements	7-9
7-2	CBD Off-Street Parking Inventory	7-11
7-3	Location of Urban Renewal Authority Parking Lots and Current Charges	7-16
7-4	Locations and Rates at Parking Facilities	7-17
7-5	Destination Zones of Downtown Parkers by Trip Purpose	7-24
7-6	Regional Park-N-Ride Sites	7-28
8-1	Denver Bikeway System	8-4
8-2	Pilot Route Map	8-5
8-3	Bicycle Routes and Parking Facilities in Downtown Denver	8-7
9-1	RTD Jurisdiction and Primary Transit Corridors	9-4
9-2	Major Bus Routes	9-11
10-1	Population Forecasts for the Five County Denver Region	10-7
10-2	Allocation of DRCOG Population Forecasts to the City and Suburbs of the Denver Region	10-11
10-3	Allocation of DRCOG Emplouyment Forecasts to Subareas of the Four County Region	10-16
10-4	Denver Central Business District	10-20
10-5	Recent Trends in CBD Retail Sales by Product Line	10-22
10-6	Office and Retail Core of Denver Central Business District	10-47
11-1	The Travel Choice Hierachy	11-4
11-2	Average Fuel Consumption and CO Emission Cold Start Curves	11-7
11-3	Percent Change in Daily Vehicle Miles of Travel	11-14
11-4	1985 Projected Changes in Total Travel and Emissions	11-18
11-5	Changes in Average Household Travel and Emissions,1985-1975	11-19
C-1	Interrelationships of Travel Demand Models	C-3
C-2	Travel Demand Model Linkage - Single Household	C-11
C-3	Fuel Economy as a Function of Average Speed, by Weight Class	C-19
C-4	Fuel Economy as a Function of Weight, by Vehicle Speed	C-20
C-5	Cumulative Fuel Economy vs. Trip Length	C-22
D-1	Graph of Denver SAI Air Quality Model Results	D-13

LIST OF FIGURES continued

FIGURE		PAGE
E-1	Structure of Disaggregate Model System	E-10
H-1	Response of Healthy Adults at Light Activity to Various Carbon Monoxide Exposures	H-5
H-2	Relationship of Combustion Products to Air-fuel Mixture	H-9
H-3	Evolution of Photochemical Smog as Indicated by Average Levels of Pollution in Downtown Los Angeles	H-11
H-4	Conditions for the Formation of an Inversion	H-13

LIST OF TABLES

TABLE — PAGE

1-1 Journey to Work Patterns - Daily Work Trips 1-23
1-2 Summary, Colorado Air Pollution Control Transportation and Land Use Plan 1-27
1-3 Effectiveness of Maximum and Most Feasible Controls Available for the Denver AQCR 1-28
1-4 Effect of Colorado and EPA Strategies by 1977 1-30
1-5 Denver Transportation System Management Element 1-35
1-6 Colorado State Energy Conservation Plan 1-36
1-7 Potential Impacts of Transportation Control Plan Implementation 1-43

2-1 DRCOG's 1976 Budget by Program Category 2-20
2-2 Summary of Agency Involvement in TCP Measures 2-33

3-1 Percent of Total Areawide Emissions Contributed by Each Major Source Category 3-9
3-2 Violations of One-Hour Carbon Monoxide Standards 3-12
3-3 CAMP Station 1-Hour Violation Days 3-13
3-4 Violations of Eight-Hour Carbon Monoxide Standards 3-14
3-5 CAMP Station 8-Hour Violation Days Carbon Monoxide 3-15
3-6 No. of Days in 1975 Ozone Standard was Exceeded at State Operated Stations 3-21
3-7 CAMP Station, Monthly Mean NO_2 Concentrations (ppm) 3-25
3-8 Summary of Historical Particulate Sampling Data 3-28
3-9 Summary of Denver Air Pollution Facts 3-32

4-1 Emission Reduction Versus Rejection Rate 4-39
4-2 Maintenance Costs 4-43
4-3 Inspection/Maintenance Costs - Department of Health 4-44
4-4 Inspection and Maintenance Costs - Department of Revenue 4-46

5-1 Chronology of Denver Ride Sharing 5-8
5-2 Employers Subject to APCC Regulation 9 5-9
5-3 Employer Ride Sharing Plans 5-11
5-4 Employer Incentives 5-14
5-5 Carpool Program Expenditures by Urban Area 5-17
5-6 DRCOG Carpool Program Benefits Estimate 5-21
5-7 Transit Availability for Denver Work Trips 5-23
5-8 List of Firms Employing Selected Transit Incentives 5-24
5-9 VMT Reduction Potential of Employer-Based Ride Sharing 5-40

6-1 Peak Period Bus Volumes on 16th and 17th Streets 6-30
6-2 Average Passenger Loads on Express Buses Using 16th and 17th Streets 6-30
6-3 Express Bus Volumes and Ridership on Boradway-Lincoln 6-32
6-4 Bus Travel Times 6-33
6-5 Automobile Travel Times on 16th and 17th Streets 6-33
6-6 Automobile Travel Times on Broadway and Lincoln 6-34
6-7 Traffic Volume Changes on 16th and 17th Streets 6-37
6-8 Traffic Volume Changes in Broadway-Lincoln Corridor 6-37
6-9 VMT, Fuel, and Emissions Potential of 5% Improvement in In-Vehicle Travel Time 6-43
6-10 Summary of Preferential Bus Lane Projects 6-46

LIST OF TABLES continued

7-1 Example Parking Management Measures 7-2
7-2 Possible Impacts of Parking Measures 7-3
7-3 Proposed Rates at Denver Center for Performing Arts Garage 7-14
7-4 DPW Parking Revenues 7-14
7-5 Trip Purposes of Parkers with Center City Destinations, Average Weekday January, 1970 7-21
7-6 Peak Accumulation - Capacity by Facility Type 7-23
7-7 Example - CBD Oriented Parking Management Measures % Change from Base (CBD Work Trips) 7-31
7-8 Example - Areawide Parking Management Measures % Change from Base 7-32

8-1 Construction Expenditures for Denver Bikeways 8-21
8-2 Modal Survey of Denver Downtown Colleges and Businesses 8-23

9-1 VMT Reduction Potential of 25% Reduction in Bus Headways % Change from Base, Areawide 9-22
9-2 VMT Reduction Potential of CBD-Oriented Transit Policies % Change from Base (CBD Work Trips) 9-24

10-1 Employment Forecasts for the Denver Region 10-13
10-2 Distribution of Non-Residential Floorspace in the Denver CBD, 1975 10-19
10-3 Retail Sales in the CBD, Constant Dollars of 1967, By Product Line 10-23
10-4 Impacts of European ARZ's 10-32
10-5 Impacts of US ARZ's 10-33
10-6 Aggregate Retail Sales Model Results 10-38
10-7 Disaggregate Retail Sales Model Results Denver CBD 10-42
10-8 Employment in the Office and Retail Core of the CBD 10-46
10-9 Office Space in the CBD 10-46
10-10 Vacancies for a Sample of Office Buildings in the CBD and in the rest of the Denver Region 10-49

11-1 Interrelationship of Automobile Ownership, Work and Non-Work Travel 11-6
11-2 Alternative Program Packages 11-11
11-3 Predicted Areawide Work Trip Modal Share Impacts of Program Packages 11-12
11-4 Predicted Areawide Impacts of Program Packages 11-13
11-5 Marginal Effectiveness of Alternative Program Measures, 1985 Work Trip Impacts 11-21
11-6 Marginal Effectiveness of Alternative Program Measures, 1985 CBD Work Trip Impacts 11-22

C-1 Independent Variables Incorporated in Travel Demand Model System C-6
C-2 Model System Representation of Transportation Measures Analyzed C-16

D-1 Basic High Altitude Emissions Factors D-4
D-2 Speed Correction Data for the FTP Method D-5
D-3 Temperature Correction Coefficients D-6
D-4 Coefficients for the Cold Operation Correction Factor D-8
D-5 Derivation of Model Year Weighting Factors D-9
D-6 Summary of Auto Contributed Emissions D-14

LIST OF TABLES continued

TABLE		PAGE
E-1	Aggregate Model of Retail Sales (1970), Empirical Results	E-7
F-1	Economic and Demographic Data, Central Area, City and County of Denver, Balance of Four County Region	F-3
F-2	Number of Daily Work Trips	F-5
G-1	Land Use and Transportation Inputs to SAI Model	G-3
G-2	Air Quality Inputs to SAI Model	G-4
H-1	National Ambient Air Quality Standards	H-3
H-2	Impacts of Exposure to Carbon Monoxide	H-7
H-3	Threshold Exposure Levels for Adverse Health Effects from Smog	H-15

CHAPTER 1

INTRODUCTION

PROJECT OBJECTIVES AND BACKGROUND

Many American cities must reduce total automotive emissions in order to meet the national ambient air quality standards promulgated by the U.S. Environmental Protection Agency (EPA) under the authority of the Clean Air Act. The 1970 Clean Air Amendments called for implementation of programs to reduce emissions from transportation sources - transportation control plans (TCPs) - in order to attain the standards no later than 1977. However, the control plans met stiff opposition in a number of cities, and almost everywhere, implementation was slow. By 1977 it was apparent that many urban areas would not meet the air quality standards by the deadline. Partly in response to that situation, Congress provided for extensions to the deadlines in the 1977 Clean Air Amendments (1).

Several studies have investigated the causes of controversy and delay in implementation of transportation measures to improve air quality over the 1973-1976 period (2). The studies note confusion over legislative requirements, difficulty in responding to tight deadlines, and lack of consensus on the air quality problem's severity and implications. In addition, they note that a major problem has been the lack of experience with the specific transportation measures proposed. Incomplete information about the effectiveness, costs, and feasibility of these transportation measures has caused delays; failure to investigate social and economic effects of proposed strategies has fed controversies. The need for better information on both the measures and air quality transportation planning procedures is recognized widely.

The research presented here was initiated in order to answer many of the questions which have arisen about the costs of transportation actions to improve air quality and about the institutional requirements, administrative support and planning procedures needed to achieve effective implementation. A case study of implementation experience with the Denver, Colorado transportation control plan provided the information base to meet the study objectives:

- to identify and determine the relative importance of various costs and benefits associated with the implementation and administration of various transportation controls, and to identify the particular groups affected by the controls.
- to demonstrate via a case study analysis various methodologies available both to identify and to forecast the magnitude of important impacts.
- to determine the degree of transferability of the case study results to other cities.

The choice of a single case city facilitated an in-depth analysis of six of the transportation measures most frequently proposed as ways of improving air quality. They are:

- vehicle inspection and maintenance
- employer based ride sharing
- preferential treatment of high occupancy vehicles
- parking management
- improved bicycle facilities
- improved transit

These measures when implemented singly or in combination may result in a variety of impacts on the transportation user, urban area businesses, and governmental agencies. Relatively inexpensive "sketch planning" analysis methodologies have been used to examine potential travel, air quality, fuel consumption, and economic consequences. In addition, major attention has been devoted to a realistic assessment of the institutional requirements necessary for successful implementation - examining the administrative requirements within those governmental agencies assigned implementation responsibilities as well as the requirements for coordination between these assigned agencies.

The research is designed to be of use to the Department of Transportation (DOT) and the Environmental Protection Agency in meeting their responsibilities under the 1977 Clean Air Act Amendments, and to the state, regional, and local agencies and groups who will have responsibilities for - or at least a strong interest in - the transportation actions which must be commenced over the next few years to attain clean air. This report presents the case study findings and describes methodologies which should be usable by other areas in developing and analyzing their own transportation/air quality plans and programs. In the remainder of this chapter, background information is presented on transportation/air quality planning experience under the 1970 Clean Air Amendments, on the Clean Air Amendments of 1977, and on the Denver case study context and the analysis framework. Chapter 2 examines Denver's institutional arrangements and their effect on transportation/air quality planning, and Chapter 3 reviews the Denver air quality problem. The next six chapters examine each of the program measures proposed for the Denver Region. Chapter 10 examines potential economic impacts of transportation/air quality measures, and Chapter 11 presents information on their overall effectiveness. Chapter 12 summarizes the study findings and conclusions and presents recommendations.

TRANSPORTATION/AIR QUALITY PLANNING

Experience Under the 1970 Amendments

The Clean Air Act Amendments of 1970 directed the Environmental Protection Agency to establish national ambient air quality standards whose attainment would protect the public health and welfare. The Act established three major methods for achieving the air quality standards:

1) increasingly stringent emissions controls on new automobiles;
2) performance standards for appropriate categories of new stationary emissions sources; and
3) State Implementation Plans (SIPs) containing any additional control regulations and other measures needed to achieve the air quality standards within each state's boundaries

The standards for two pollutants, photochemical oxidants and carbon monoxide (CO), are exceeded in most large urban areas, primarily as the result of motor vehicle emissions of CO, hydrocarbons (HC), and nitrogen oxides (NO_x). Although the new car emissions standards and stationary source controls have produced substantial emission reductions, many cities require additional actions to achieve the carbon monoxide and oxidant standards. Most frequently, these actions are in the form of transportation measures directed at reducing either vehicle miles of travel or vehicle emissions themselves.

The 1970 Amendments placed initial responsibility for the development of SIPs, including transportation control plans (TCPs), with the states. However, the Act required EPA to supplement any inadequate state plan (or sub-area plan) and to formulate a plan for the state if the state should fail to do so. TCP development began in 1973, but it soon became apparent that the notion of transportation control was meeting stiff opposition in many cities. Although some approvable plans were submitted, EPA was required to develop and issue transportation control measures for a large number of urban areas. Subsequent efforts to implement control measures set off heated and often antagonistic debate in a number of metropolitan areas. Criticisms of, and challenges to, proposed measures led to repeated plan revisions and delays in implementation in many cases.

Investigations of the TCP's development and reception have identified several problems, including (2):

1) Uncertainties about the nature and severity of the air pollution problems facing metropolitan areas and about the health and welfare effects of air pollution;

2) Constraints imposed on the transportation control planning process by strict statutory deadlines and limited resources;

3) Incomplete information about the effectiveness, costs, and implementability of transportation control options;

4) Credibility problems (often stemming in part from uncertainties and incomplete information); communication breakdowns among agencies and with the public; and minimal citizen participation (often due in part to tight deadlines);

5) Failure to explicitly investigate social and economic effects of proposed transportation control strategies, resulting in controversy over the perceived costs and benefits of the measures;

6) Lack of interdisciplinary skills available to transportation control planning bodies, resulting in undue limitations on the alternatives considered and hampering identification on the effects of proposed strategies;

7) Failure to adapt the transportation control planning process to the existing institutional framework, resulting in inefficient use of resources and lost opportunities;

8) Emphasis on regulation with insufficient attention to planning needs;

9) Insufficient guidance for state agencies' planning;

10) Emphasis on the development of a specific plan with insufficient attention to developing a viable, long-term planning process.

Some of these problems stemmed directly from the 1970 Amendments. In particular, the tight deadlines were a severe constraint on the amount of analysis which could be performed prior to the required date for plan submission. Uncertainty about the nature and scope of the air pollution problem and its attendant health effects, inadequacy of the air pollution data available to planning agencies, and inexperience in assessing the air quality effects of transportation measures also made it difficult to convincingly define an area's air pollution problems and the steps necessary to correct them.

A general lack of public understanding of the sources of air pollutants, their effects, and measures necessary to reduce emissions was exacerbated by the absence of public information and public participation programs during the development of air pollution control measures. The consequences of this have been particularly severe when the pollution source to be regulated is one owned by most American families. Perhaps the most important reason for the development of controversy over transportation control plans, however, was the failure to adequately consider the full range of their potential impacts and the distribution of these impacts among different sectors of the public. Common objections have been that transportation control measures would reduce the competitive position of the central city in terms of retail sales and employment, would adversely affect construction and other development throughout the region and cause undesirable land use shifts, would seriously reduce mobility for the average citizen, or would place a harsh financial burden on local governments for implementation and enforcement of the measures. With a few exceptions, there have been no sound data or analysis to adequately support or refute such charges.

Certainly, time pressures and resource limitations were factors in the failure to assess these impacts, but equally important were the inexperience with the control measures themselves and lack of information about their costs, effectiveness, direct and indirect and short-term and long-term effects, implementation requirements, and other important considerations.

Uncertainties about the legal status of transportation control plans also plagued the program practically from the start. Initially, the EPA Administrator advised the states that the submission of transportation control plans could be deferred until February 1973, to allow additional time for the development of control strategies. In addition, the Administrator granted extensions for the attainment of the air quality standards on the grounds that the transportation measures would not be available soon enough to permit attainment within the time prescribed by the Act. In some cases, the extension meant that air quality control regions' transportation strategies would be targeted to a 1977 deadline. Certain other air quality control regions would not have to develop transportation control strategies at all; motor vehicle emissions reductions and stationary source controls in the 1975-77 period would be adequate to meet the standards. However, the granting of additional time for transportation control plans was overturned by the federal courts, who required EPA to rescind its extensions for submission of the plans and also to rescind the extension granted to several states to delay implementation until 1977 (3,4). The Administrator was ordered to require submission of complete SIPs meeting the Clean Air Act requirements (i.e., including detailed transportation/land use control strategies where necessary) by April 15, 1973. Thus, several states were notified in February 1973 that, within six weeks, they were to submit a plan showing attainment of the standards by 1975 instead of 1977. Most states found it impossible to respond so quickly, and EPA had to prepare plans for them.

A second major legal issue was whether EPA had authority to require state and local governments to implement the transportation control plans EPA promulgated. The majority of the Circuit Courts that ruled on the issues rejected EPA's claims of authority to require states to spend money or pass legislation to implement the control plans, and hinted that EPA's option would be to implement control strategies itself, e.g., run its own vehicle inspection and maintenance programs, carpool matching systems, and so on (5). The Supreme Court agreed to review the cases in 1977, but sent the cases back for reconsideration in light of pending changes in the plans instead of deciding the enforceability issue (6). Uncertainties over the enforceability of TCPs made state and local agencies reluctant to implement unpopular portions of the plans and made EPA (and its state and regional counterparts) reluctant to push too hard for action.

In recognition of these problems in implementing transportation control plans, EPA began to urge states and urban areas to develop their own strategies which would meet multiple objectives - energy conservation, more efficient use of transportation facilities, and various specific local goals as well as air quality improvements. This approach encouraged considerable "piggybacking" on other federal policies, in particular the transportation systems management requirement of DOT's Federal Highway and Urban Mass Transportation Administrations and the State Energy Conservation Program objectives of the Department of Energy (DOE)(7). Although some successes in integrating these various planning activities emerged, implementation of measures which would improve air quality continued to be slow. For one thing, the various objectives are not always compatible, and various measures are not necessarily equally effective in improving air quality and in meeting the other objectives (8). Because resources are limited, measures to improve air quality often had to "compete" with other actions with little air quality benefit. Furthermore, from 1976 on states and local areas were aware that Congress was considering amendments to the 1970 clean air legislation and were understandably reluctant to devote time and money to a major transportation air quality planning effort until the new requirements were clear.

In view of this continued slowness to implement air quality measures, EPA (as well as others) has directed increasing attention in the past three years to the processes through which transportation measures to improve air quality are developed, analyzed, and implemented. Experience in the early phases of transportation control planning had concentrated on the specifics of the product - the measures themselves - without sufficient attention to the institutional arrangements, assignments of responsibility, sources of funding, and social, economic, and environmental impacts which largely determine the feasibility of bringing proposed projects into being. EPA has moved to correct that deficiency by emphasizing the need for ongoing procedures for considering the air quality implications of various transportation actions. The 1970 Federal-Aid Highway Act's requirement for consistency between SIPs and highway projects (5) has provided impetus for bringing air quality considerations explicitly into the transportation planning process, and (as the next section shows) recent changes in federal law should accelerate this.

The Clean Air Act Amendments of 1977

The 1977 Clean Air Act Amendments (1) make sweeping changes to the procedures through which transportation-based air quality improvement measures are to be developed and implemented. Many of the new provisions were designed to avoid problems which occurred in transportation control planning under the 1970 Amendments. Other provisions clarify the responsibilities of the Department of Transportation and other agencies in support of actions to reduce air pollution.

The state implementation plan (SIP) remains the foundation for transportation-related air quality attainment; The new amendments provide for extensions to 1987 for attainment of the standards for carbon monoxide and photochemical oxidants. If no extension is granted, the attainment deadline is December 31, 1982 (Sec. 172). State, regional, and local officials in nonattainment areas must jointly determine which planning, implementation and enforcement responsibilities each level of government will assume; where feasible, the MPO or the air quality maintenance organization should be responsible for the air quality planning process (Sec. 174). By January 1, 1979, nonattainment areas must submit implementation plans either showing attainment of the carbon monoxide and oxidant standards by 1982 or demonstrating to the satisfaction of EPA that such attainment is not possible despite the implementation of all reasonably available measures. (Current SIP provisions remain in effect unless modified or deleted through the 1979 revisions.) In cases where such a demonstration is made, the 1979 SIP submission must establish a program of alternatives analysis prior to issuance of construction or modification permits to emitting facilities; must establish a specific schedule for implementing a vehicle inspection and maintenance program; and must identify all other measures necessary to attain the standards not later than 1987. In addition, the 1979 submission must include evidence on comprehensive measures to establish, expand, or improve public transit as expeditiously as possible, with appropriate funding commitments, and to implement other transportation measures necessary to attain and maintain the standards. Reasonable further progress toward attaining the standards must be shown on an annual basis. Areas who are granted an extension beyond 1982 must submit a SIP revision by July 1, 1982, that contains enforceable measures to assure attainment as expeditiously as practicable but not later than 1987. Both the 1979 and 1982 plans submitted to EPA must include not only measures to insure attainment and maintenance of the standards, but also schedules and timetables for compliance (Sec. 110) and other evidence of the necessary commitments to implement and enforce the plan provisions (Sec. 174). Plan provisions must be adopted or promulgated after notice and reasonable public hearing, and considerable emphasis is placed on extensive consultation among agencies, public education and participation, involvement of elected officials, and the documented analysis of a wide range of alternative measures (Sections 121, 127, 172, 174, and 178). After July 1, 1979 or 1982 (depending on the extension status), if a nonattainment area has not submitted or made reasonable efforts toward submitting an adequate plan, EPA cannot approve projects or award grants authorized by the Amendments, and DOT cannot approve projects or award grants under Title 23 U.S.C. other than for safety, mass transit, or transportation improvement projects related to air quality improvement or maintenance in that area (Sec. 176).

The amendments encourage the inclusion of programs for improved transit, exclusive bus and carpool lanes, on-street parking control, park and ride a vehicle inspection and maintenance program; and must identify all other measures necessary to attain the standards not later than 1987. In addition, the 1979 submission must include evidence on comprehensive measures to establish, expand, or improve public transit as expeditiously as possible, with appropriate funding commitments, and to implement other transportation measures necessary to attain and maintain the standards. Reasonable further progress toward attaining the standards must be shown on an annual basis. Areas who are granted an extension beyond 1982 must submit a SIP revision by July 1, 1982, that contains enforceable measures to assure attainment as expeditiously as practicable but not later than 1987. Both the 1979 and 1982 plans submitted to EPA must include not only measures to insure attainment and maintenance of the standards, but also schedules and timetables for compliance (Sec. 110) and other evidence of the necessary commitments to implement and enforce the plan provisions (Sec. 174). Plan provisions must be adopted or promulgated after notice and reasonable public hearing, and considerable emphasis is placed on extensive consultation among agencies, public education and participation, involvement of elected officials, and the documented analysis of a wide range of alternative measures (Sections 121, 127, 172, 174, and 178). After July 1, 1979 or 1982 (depending on the extension status), if a nonattainment area has not submitted or made reasonable efforts toward submitting an adequate plan, EPA cannot approve projects or award grants authorized by the Amendments, and DOT cannot approve projects or award grants under Title 23 U.S.C. other than for safety, mass transit, or transportation improvement projects related to air quality improvement or maintenance in that area (Sec. 176).

The amendments encourage the inclusion of programs for improved transit, exclusive bus and carpool lanes, on-street parking control, park and ride exercise of such authority to implementation of air quality plan provisions, and specifies that the section extends to authority exercised under the Urban Mass Transportation Act, Title 23 U.S.C., and the Housing and Urban Development Act. Furthermore, Section 176 stipulates that no federal agency shall engage in, support, financially assist, license, or approve any action which does not conform to an air quality plan, nor shall any MPO approve any nonconforming plan, program, or project. Finally, Section 176 prohibits EPA from making grants under the Clean Air Act in any area where the state, designated agency, or local government(s) fails to implement any requirement of a SIP.

At the time of this writing, the guidelines for the transportation/air quality planning process are in the draft stage. Lead agency designation should be completed by April 1, 1978, and many MPOs have begun efforts on the January 1, 1979 SIP.

THE DENVER CONTEXT

Urban Area Characteristics

Denver, the capital and largest city of Colorado, is the wholesale, service, manufacturing, research, and governmental center for a large portion of the Great Plains and mountain states (Figure 1-1).[1] Situated just east of the Front Range of the Rocky Mountains, the city is known for its attractive environment. Nevertheless, Denver's high altitude, its topography, and its heavy auto use result in high levels of air pollution. Measurements have shown that Denver exceeds the primary national ambient air quality standards for both carbon monoxide and photochemical oxidants on 70-150 days of the year, which ranks Denver among the worst polluted American cities. However, on this ussue as on other issues concerning growth and the environment, there is a split of opinion about whether Denver has a serious problem. Strong anti-pollution laws and active environmental agencies are evident, but there also are many who believe that environmentalists and no- or slow-growth advocates have seriously overstated their case. The plans developed for Denver reflect these divergent attitudes concerning the future of the area; widely varying population estimates, land use and development plans, and transportation systems have been proposed at various times.

Since 1930, Denver's growth consistently has been twice to three times

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[1] References to the Denver region generally include Adams, Arapahoe, Denver, and Jefferson Counties. Boulder County, which is less closely linked to Denver than the other suburban counties, also is included in references to the region when so noted. Douglas and Gilpin Counties, which currently are sparsely populated, will be included in the SMSA in the 1980 Census. The central area (CBD) encompasses roughly all of the land between Federal and Colorado Boulevards, on the West and East, respectively, and between 38th and 6th Avenues on the North and South.

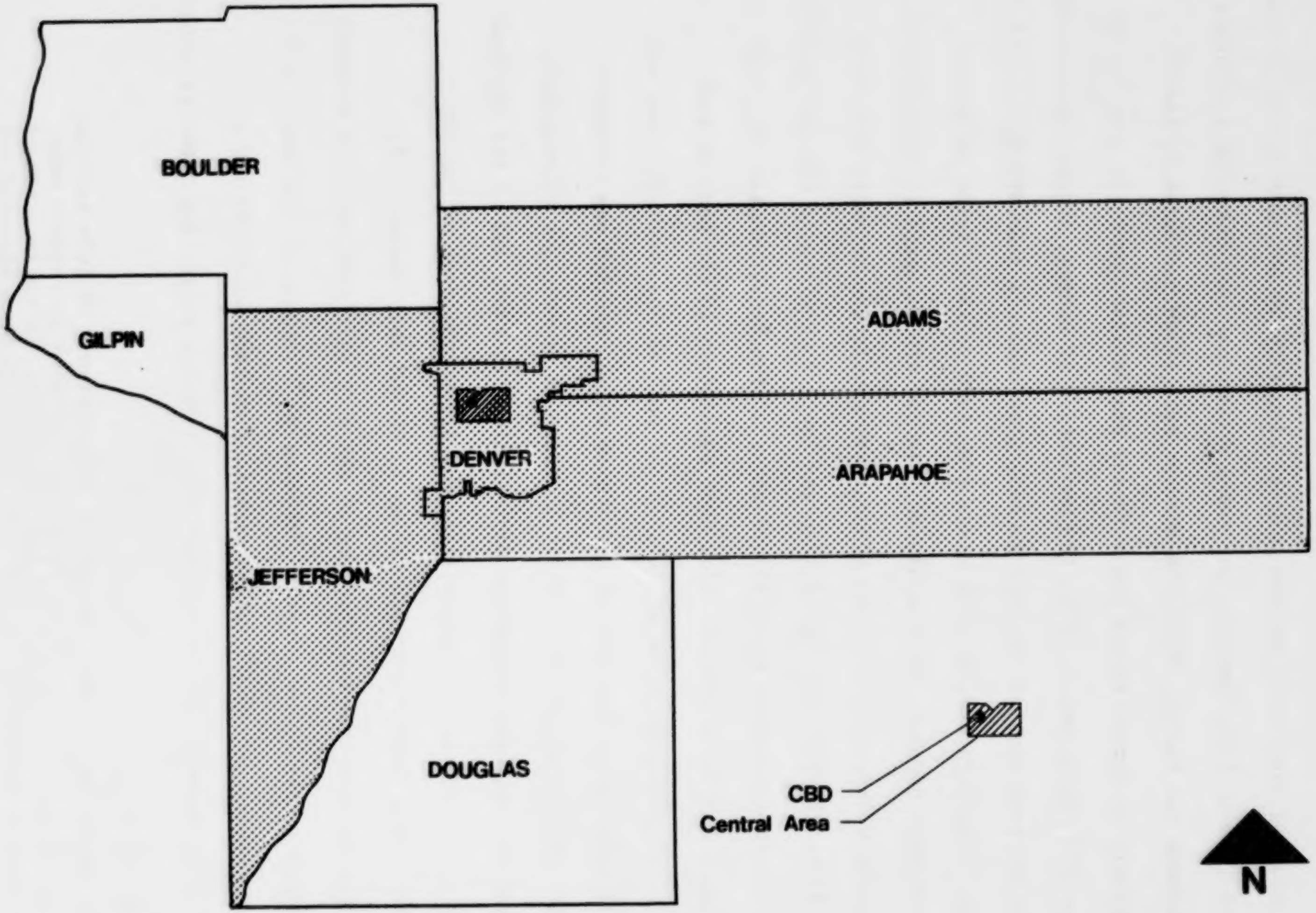
BOULDER
GILPIN
ADAMS
DENVER
ARAPAHOE
JEFFERSON
DOUGLAS
CBD
Central Area
N

FIGURE 1-1

Denver and Surrounding Counties

the national rate, with an even greater disparity in the most recent five-year period (Figure 1-2). However, the rapid growth has been unevenly distributed throughout the region. While the suburbs have grown explosively, the City and County of Denver itself has suffered the decline common to many cities since 1960. From 1960 to 1970, the population of Denver, including territory which had been annexed over the decade, grew modestly from 493,887 to 514,678. Further growth to 527,100 took place from 1970 to 1975, again including annexations. However, when population figures are adjusted to include only territory within Denver's 1960 boundaries, population actually fell from 493,887 to 474,162 over the sixties and further declined to 456,000 by 1975.[1]

Population trends in different parts of the Denver region are shown in Figure 1-3. From 1960 to 1975, lost population in the central area totaled 27,384, a decrease of 20%. In the rest of the city, the loss was 10,503 (3%), while the rest of the region gained 486,658 new residents (135%). These dramatic disparities in rates of growth have substantially altered the regional population distribution. In 1960, 16% of the regional population lived in the central area and 41% in the rest of the city. By 1975, these percentages had fallen to 9% and 26%, respectively. Both the central area and the rest of the city also have suffered economic decline relative to the suburbs. Families with incomes in the lowest 40% of the region's household income distribution have accounted for an increasing share of the city's families in recent years. The opposite trend

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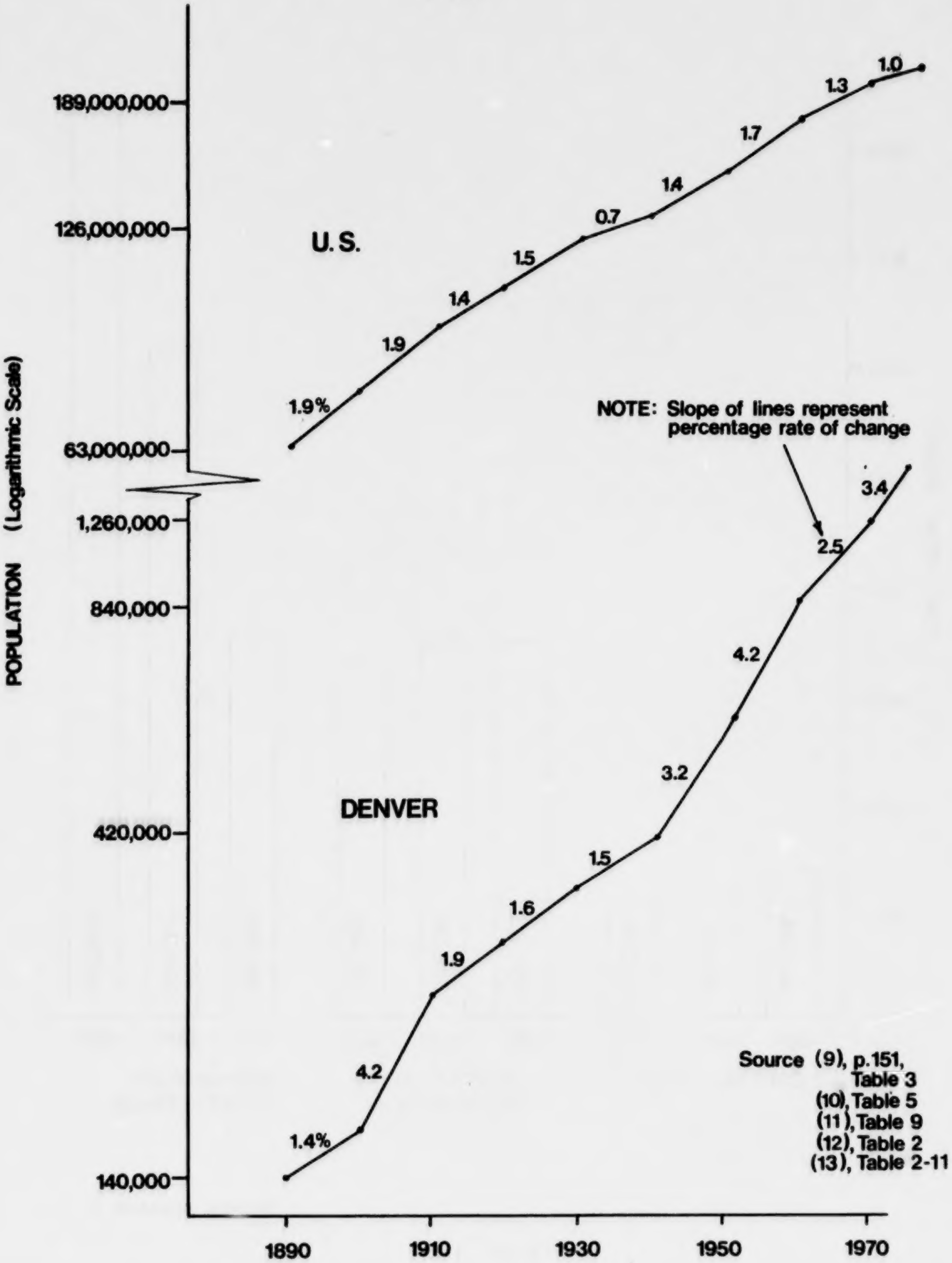
[1] For the discussion of these trends in the remainder of this section, all data for the City of Denver have been adjusted to include only that part of the city within its 1960 boundaries. An explanation of the adjustment methodology and a table presenting both adjusted and unadjusted data are found in Appendix F.

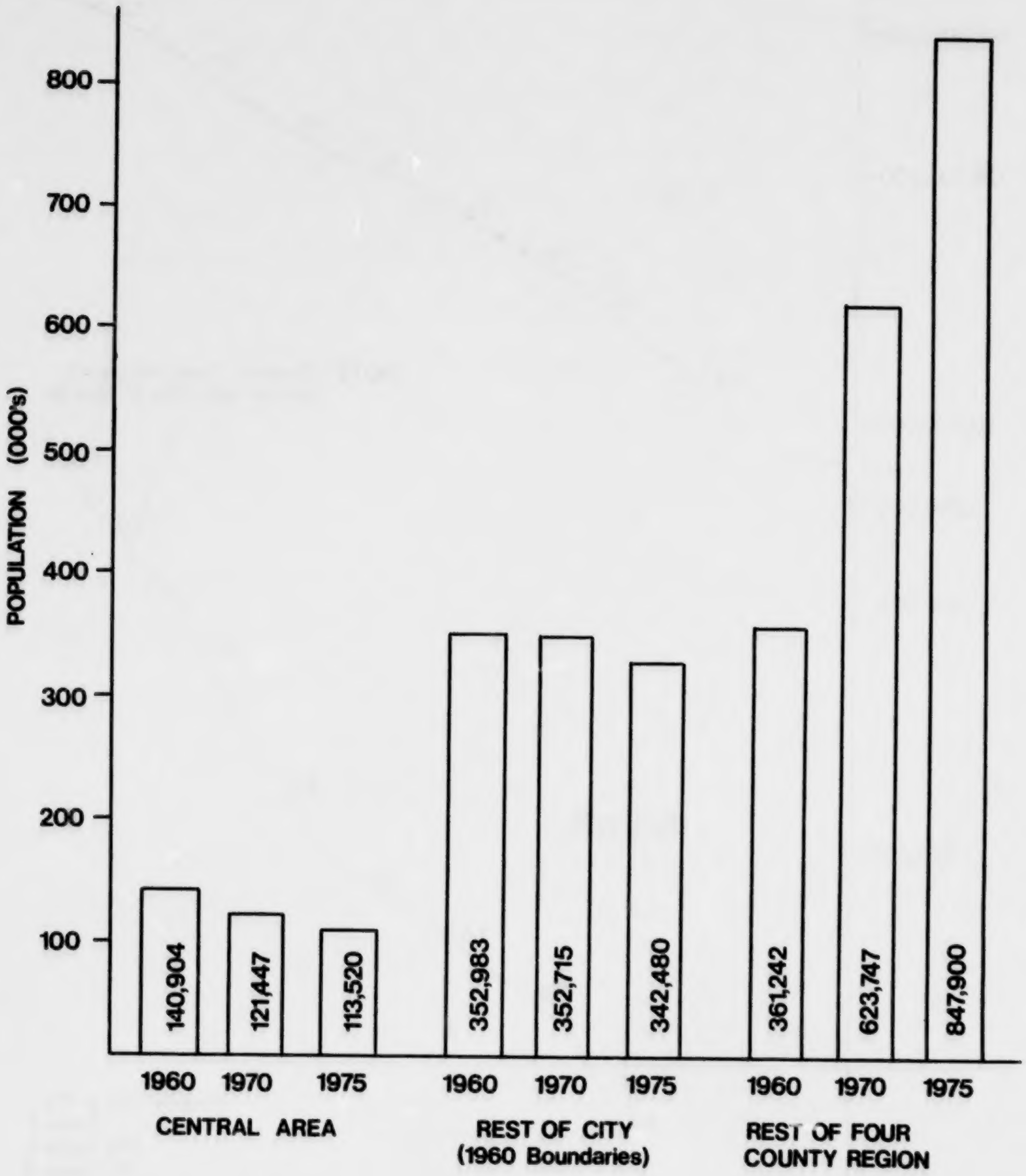


NOTE: Slope of lines represent percentage rate of change

Source (9), p.151, Table 3
(10), Table 5
(11), Table 9
(12), Table 2
(13), Table 2-11

FIGURE 1-2

Population of the United States and the Four County Denver Region



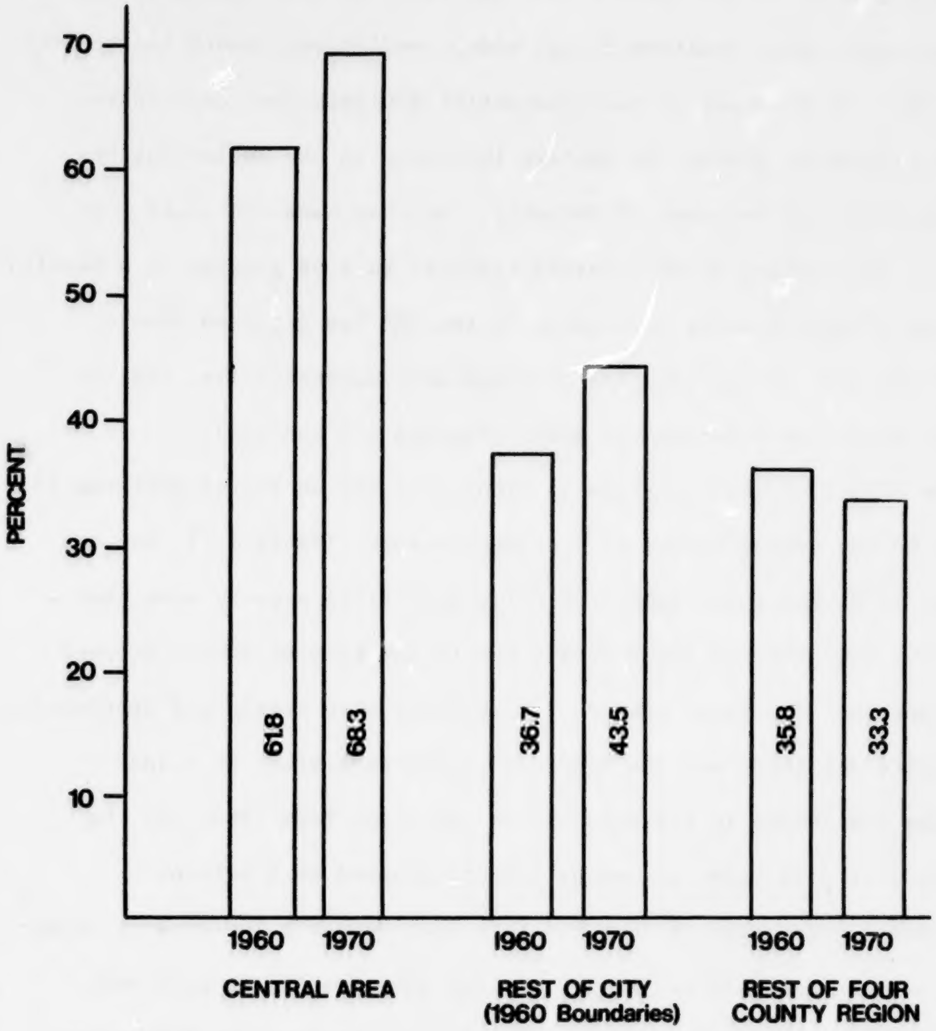
Source: Appendix F

FIGURE 1-3

Recent Population Trends in the Denver Region is apparent in the suburbs (Figure 1-4). Growth of employment also has been much greater in the suburbs than the city, in both absolute numbers and percentage rate. Positive though modest employment growth has occurred in the city, in contrast to the substantial declines that have characterized population trends. Percentage increases in CBD employment have exceeded those for the rest of the city, but they have not quite kept pace with the suburbs or the overall regional rate of growth. As a result, the share of metropolitan employment in the CBD has declined slowly; that in the rest of the city has declined more substantially; and the suburban share has consistently grown (Figures 1-5 and 1-6).

The effect of these changes in urban activity on travel patterns is evident in the Census survey of journeys-to-work. (Table 1-1). Between 1960 and 1970, the total number of daily work trips grew by more than a third, but the share of those work trips to the City of Denver dropped by ten percent. The total number of work trips with origin and destination in the city declined, and the greatest growth took place in trips beginning and ending in the suburbs. In addition, from 1960-1970 the proportion of work trips served by transit dropped by 5 percent.

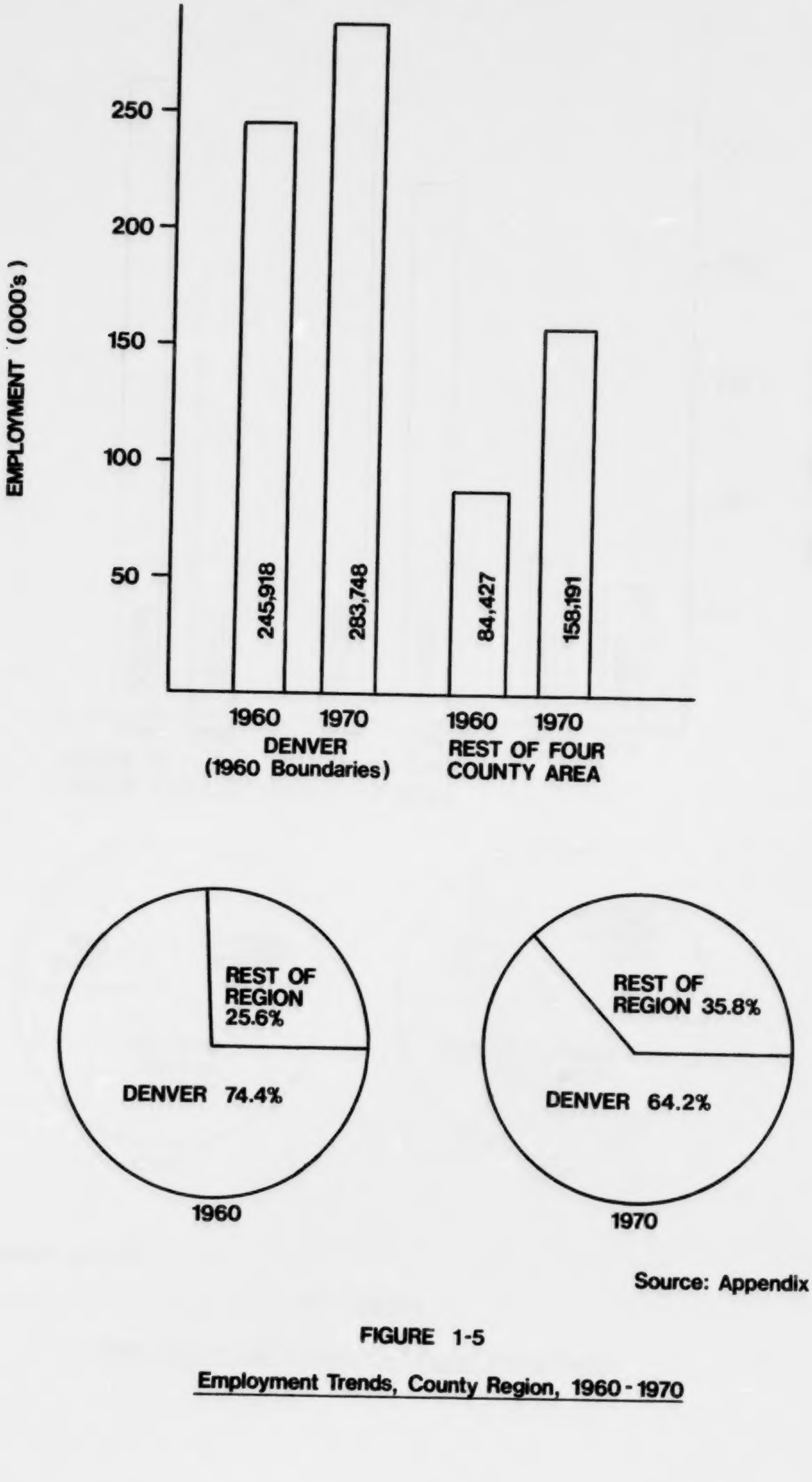
These figures also reflect the fact that Denver's low-density development pattern and well-engineered streets make driving an auto easy. An extensive grid of major arterial streets complements two interstate highways. (The Colorado Department of Highways (CDH) has not been able to build the southern portion of an interstate loop, I-470, which was halted by controversy over its environmental impacts). In addition, Denverites have an average of 1.46 autos per household, one of the highest ownership rates in the nation. The average auto occupancy rate of 1.14 is one of the nation's lowest.



Source: Appendix F

FIGURE 1-4

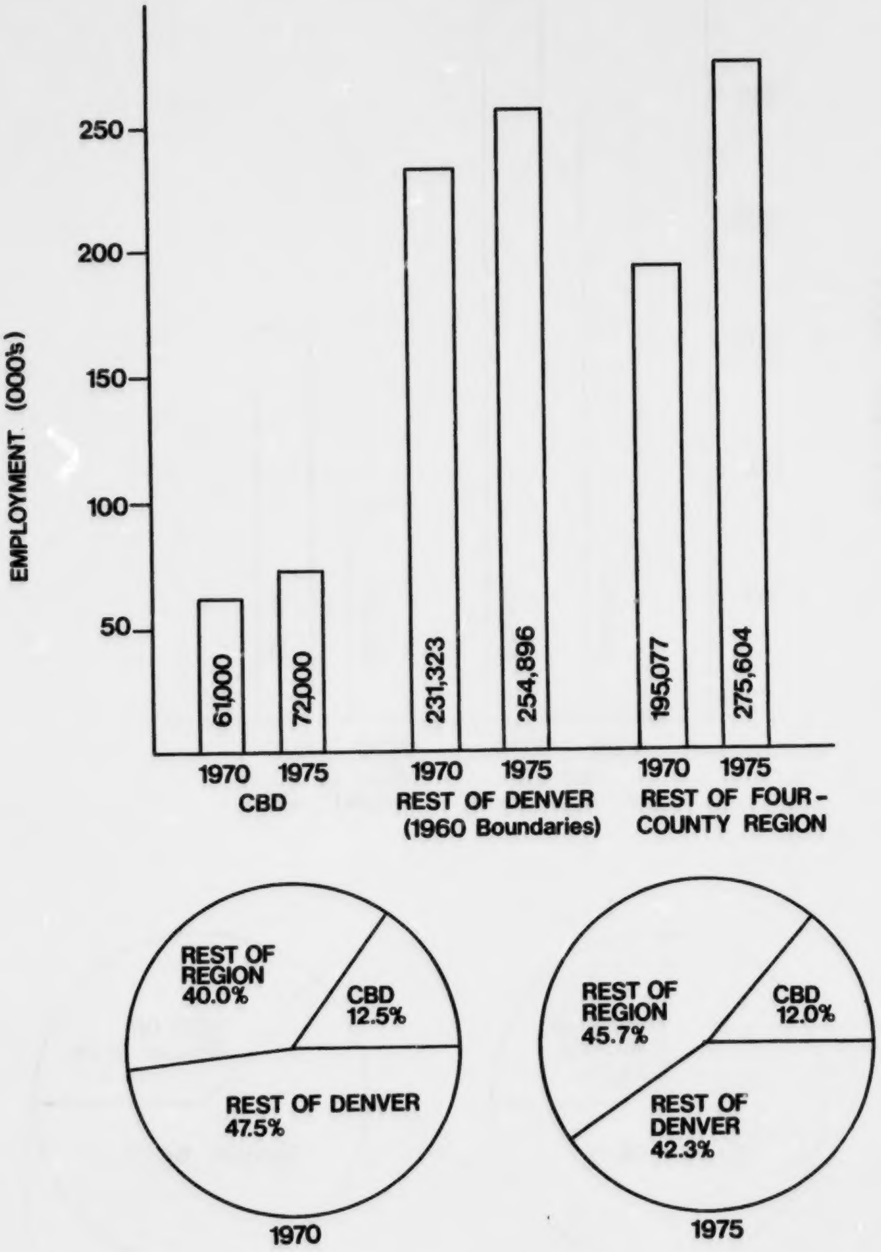
Proportion of All Families in the Lower 40 Percent of the Regional Income Distribution



Source: Appendix F

FIGURE 1-5

Employment Trends, County Region, 1960 - 1970



Source: Appendix F

FIGURE 1-6

Employment Trends Four-County Region, 1970-1975

TABLE 1-1

Journey to Work Patterns - Daily Work Trips*

	1960 All Modes	1960 Transit	1960 Transit Share	1970 All Modes	1970 Transit	1970 Transit Share
Work in Denver						
Live in Denver	165,723	27,429	16.6%	156,321	14,730	9.4%
Live in Suburbs	63,515	3,233	5.1%	106,069	2,780	2.6%
Work in Suburbs						
Live in Denver	17,021	686	4.0%	22,939	764	3.3%
Live in Suburbs	84,107	769	0.9%	168,861	1,573	0.9%
Total	330,366	32,117	9.7%	454,190	19,847	4.4%

*includes Boulder County

Source: Appendix F.

Despite this auto orientation, there is substantial support for transit in the Denver area. A strong transit agency, the Regional Transportation District (RTD), was established by the Colorado legislature in 1969 after extensive lobbying by a wide range of interests. RTD has upgraded bus service extensively and has reversed declines in ridership in the years since 1970, although (as is the case for practically all transit systems) this performance has required public assumption of large operating deficits and capital costs. However, efforts in planning a fixed guideway transit system have been less successful; in 1976 DOT's Urban Mass Transportation Administration (UMTA) rejected RTD's application for a grant supporting a light rail project. Since then, RTD's attention has been focussed primarily on corridor and CBD bus improvements. A proposed bus mall in the heart of of the CBD is the focus of much of RTD's current effort.

The Denver Regional Council of Governments (DRCOG) is the designated metropolitan planning organization (MPO) and also the designated regional clearinghouse called for in the U.S. Office of Management and Budget's (OMB) Circular A-95. DRCOG is responsible for transportation and land use modelling and forecasting, but the organization has no implementation powers. It has no land use control authority, and CDH and RTD do the highway and transit planning. Like many councils of government, DRCOG is sensitive to the concerns of its voluntary constituents and attempts to avoid controversy. The City and County of Denver, which function as a single jurisdictional unit, also play an active role in Denver transportation planning, through its influential mayor, its powerful Department of Public Works, and to a lesser extent, other city departments.

Air pollution control responsibilities reside with the Colorado Air Pollution Control Commission (APCC), a quasi-independent body located in the state's Department of Health (DOH). The APCC, whose nine members are appointed to four year terms, receives staff assistance from the Air Pollution Control Division (APCD) of the DOH. APCC is responsible for the control and abatement of air pollution from both stationary and mobile sources and for promulgating regulations to carry out such control and abatement. Their Regulation No. 9 calls for studies and actions to implement the Denver area's TCP.

The Denver Transportation Control Plan

Denver's transportation control plan, like those of many other cities, evolved over a period of years through a series of studies. The Denver Air Quality Control Region was one of several selected by EPA for prototypical development of transportation control plans. TRW Systems completed the Denver TCP prototype in December 1972, working closely with a parallel DOH-sponsored Northrop Corporation study on vehicle inspection and maintenance. TRW recommended the following measures for Denver (14):

- vehicle controls
    - inspection/maintenance
    - high altitude retrofit
    - pre-1968 retrofit
- VMT controls
    - regional bus network and improved service
    - peripheral parking
    - carpooling
    - removal of curb parking
- long term measures
    - land use planning
    - tax reforms affecting auto ownership and travel
    - regional public transportation system

The tax measures and other disincentives were included because it was recognized that voluntary measures such as carpooling would not be sufficient to attain the air quality standards by the deadlines. However, in a mail survey more than 75% of the respondents indicated opposition to restraints on motor vehicle utilization. Noting this resistance and a variety of limitations in the study, ranging from inadequate consideration of social, economic, and political implications to data problems and uncertainties in modelling and analysis methods, TRW did not recommend implementation of such auto restraints.

In the Spring of 1973, then-Governor John Love submitted the Colorado Department of Health Plan to EPA. This plan was prepared primarily by the Department's Air Pollution Control Division staff, with input from TRW, EPA Region VIII, and advisory committees on transportation planning and motor vehicle emissions. The plan, which is summarized in Tables 1-2 and 1-3, was designed to achieve the required emission reductions by the 1970 Clean Air Act's deadline, 1975. However, Department staff stated in their plan that they believed their proposals were neither feasible nor practical, citing excessive cost to the public, legislative restraints, non-availability of needed control materials and equipment, uncertainty of voluntary participation in ridesharing, lack of alternatives to the auto, and citizen opposition to rationing and auto restraints, among other reasons. The Department estimated that the annual direct costs of implementing the primary strategies would be $40,000,000. A request for extension of the attainment date to 1977 was submitted with the plan, which also contained a formal disclaimer that "except as required by state or federal statute, regulation, or court order to do so, the (Air Pollution Control) Commission will neither implement nor seek statutory authority to implement the 1975 Plan."

EPA negotiated with the state to obtain more commitment to implemen-

TABLE 1-2

Summary, Colorado Air Pollution Control Transportation and Land Use Plan

Primary

1. Citizen participation
2. Vehicle turnover
3. Improved mass transit (including marketing, etc.)
4. Provide "bikeways"
5. Vehicle inspection and maintenance
6. Vehicle retrofit
7. Vehicle high altitude modifications
8. Reduction of hydrocarbon evaporation losses
9. Fleet vehicle gaseous conversion
10. Gasoline rationing
11. Mechanic training

Maintenance

1. Long-term Transportation Planning - RTD
2. Land use planning
3. Complex source location land and regulation
4. Incorporation of air quality considerations into transportation planning
5. Reciprocal enforcement of parking tickets
6. Investigation required at federal level:
    a. Volatility of fuels
    b. request IRS rule to consider free parking as income
    c. National energy and fuel use policy
    d. EPA support of photochemical smog research in metropolitan Denver
    e. EPA and DOT investigate availability of mass/rapid transit vehicles
7. Improved goods movement technology and management

Contingency

1. Banning on-street parking in Denver CBD
2. Increase terminal costs (surcharge on off-street parking) in the Denver CBD
3. Decrease parking availability within the Denver Air Quality Central Region
4. Increase gas rationing program to the level required and establish a crash program for a carpooling locator service

Secondary

1. Staggered work hours
2. Four-day work week
3. Idle traffic control
4. Traffic-free zones
5. Establish carpooling locator service
6. Restoration of commuter rail service
7. Implement a "horsepower" tax
8. Bus maintenance and inspection
9. AQCR gas tax for use as transit funding base
10. Gaseous conversion of all public conveyances (common carriers)
11. Heavy duty vehicle retrofit
12. Heavy duty vehicle inspection and maintenance
13. Develop peripheral parking facilities in conjunction with transit system
14. Exclusive bus lanes established
15. Establish limited use license plates by color coding
16. Through movement only streets
17. Strict enforcement of existing parking and traffic regulations, bans on taxi cruising and special traffic flow consideration at construction sites
18. Selective restriction of vehicle use during designated months, alternate usage of public streets by last digit of license (odd or even)

TABLE 1-3

Effectiveness of Maximum and Most Feasible Controls Available for the Denver AQCR.

Strategy	Pollutant CO	Reduction HC
MAXIMUM CONTROLS		
(1) Inspection/maintenance of total vehicle population	11%	8%
(2) Retrofit of pre-1968 vehicles - oxidizing catalytic converter with vacuum spark advance disconnect	12	14
(3) Retrofit of 1968-1974 vehicles - oxidizing catalytic converter	36	37
(4) High altitude modification and tuning for 1968-1974 vehicles	19	12
(5) Gaseous fuel conversion of fleets	5	5
(6) Control of hydrocarbon emissions from stationary sources	0	6
(7) Improvement in public transportation and voluntary bike-way usage	6	4
Maximum reductions achievable	90%	86%
Reductions required for Federal standards	64%	60%
MOST FEASIBLE CONTROLS		
(1) Inspection/maintenance of total vehicle population	11	8
(2) Retrofit of 1955-1967 vehicles, lean idle/air-fuel ratio, vacuum spark advance disconnect	10	5
(3) High altitude modification and tuning for 1968-1974 vehicles	19	12
(4) Control of hydrocarbon emissions from stationary sources	0	6
(5) Improvement in public transportation and voluntary bikeway usage	6	4
(6) Gaseous fuel conversion of fleets	5	5
(7) Vehicle use restraints expressed as gasoline rationing at 33 percent level	20	20
Feasible reductions achieved	71	60
Reductions required for Federal standards	64	60

Source: (15)

tation and to add controls on vehicle miles of travel. In July, 1973, the Governor submitted a letter to EPA "to clarify and fully define the intent" of the state's plan (16). In addition to including a strong commitment to vehicle inspection and maintenance, the letter contained a commitment by APCC to promulgate EPA suggested regulations for bus/carpool lanes, control over the construction of parking, and restrictions on the use of on-street parking. A four page draft of the regulations was included. These regulations, after extensive revision and softening, were promulgated in 1974 as APCC regulation No. 9.

Following public hearings, this plan was promulgated on November 7, 1973 with publication in the Federal Register. The estimated emissions reductions relative to 1971 levels are contained in Table 1-4.

Based on the negotiations between EPA Region VIII and Colorado, EPA published the following proposed Colorado plan in the Federal Register on August 2, 1973:

1) Semiannual inspection and maintenance program using the idle test mode to be fully implemented by December 1, 1975.
2) Air bleed retrofit for pre-1968 vehicles to be fully implemented by July 1, 1976.
3) High altitude modification and tuning specifications for 1968-1975 vehicles to be fully implemented by July 1, 1976.
4) Designation of mandatory bus/carpool lanes by December 1, 1974.
5) Limitation on the construction of future parking facilities, to be implemented by December 1, 1974.
6) Removal of on-street parking in the Central Business District, to be implemented by December 1, 1974.

TABLE 1-4

Effect of Colorado and EPA Strategies by 1977

	Percent reductions from 1971 emissions	
	CO	HC
1. Federal motor vehicle control program	31	23.0
2. Inspection/maintenance	7	2.5
3. Air bleed retrofit	4	1.0
4. High altitude modifications	10	2.5
5. VMT reductions a. Bus/carpool lanes b. Parking lot construction limitations c. Limitation of on-street parking in the core area	6	5.0
6. Stationary hydrocarbon control		24.0
7. Gasoline limitation	6	5.0
Total reduction	64	63.0
Reduction required	64	60.0

7) Improvements in public transit, as proposed by Colorado's Regional Transportation District.

8) Expanded bikeway development.

Since these eight measures did not demonstrate attainment of the air quality standards by May 31, 1977, EPA included a provision for limitation of gasoline sales. (For administrative reasons, the stationary hydrocarbon emission controls were removed from the transportation control plan and issued as a separate EPA regulation.)

Technical support for the EPA plan was provided by TRW Systems (17). They estimated that a 31% reduction in projected 1977 VMT was required to meet the national ambient standards for carbon monoxide and oxidants. This was equivalent to a 15% VMT reduction in 1977, an 11% decrease in 1976, and a 7% reduction in 1975. The 7% 1975 change was based on the following:

- 2% VMT reduction from mass transit improvements sufficient to double transit ridership;
- 5% VMT reduction from bus/carpool lanes, assuming each preferential treatment facility accomplishes a 22% reduction in affected VMT and that the implemented lanes could be used by one quarter of total daily traffic.

The remaining two strategies - restriction of new parking lot growth and reduction of on-street parking - were included to prevent any growth in VMT beyond 1975 levels.

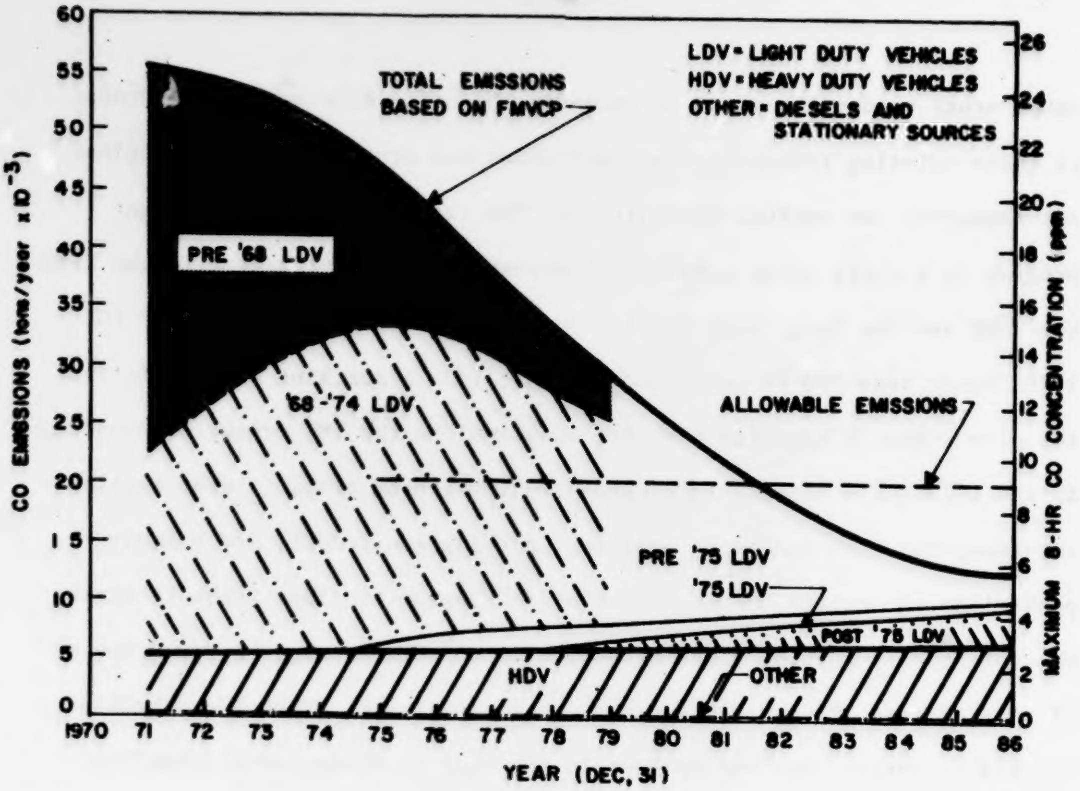
EPA acknowledged that there would be "some direct costs" associated with the plan, but that these costs "should not outweigh the benefits accrued from cleaner air " (18). Further, EPA stated that "some adjustment in travel patterns will be required...[but]...these effects will be temporary and that the mobility of the population will be increased rather than decreased due largely to the upgrading of mass transit service."

Because there was a possibility of litigation on the TCP, EPA initiated preparation of an environmental impact statement on the Colorado Plan. A first draft of an E.I.S. was prepared by GCA Corporation but was neither completed nor formally released. Still, the draft provides some interesting insights and commentary on the impact analysis available at the time. Consisting primarily of a description of physical, socio-economic, air quality, water quality, noise and solid waste conditions in Denver, the draft states that sizable reductions in regionwide VMT could not be achieved by 1975 because most of the proposed control measures would require a long lead time. The draft notes that in contrast, those measures directed at reducing tailpipe emissions are most effective in the near term and would become less useful as the Federal Motor Vehicle Control Program is implemented and as the normal turnover in Denver's motor vehicle fleet occurs. This tradeoff is illustrated in Figure 1-7, which shows that the CO standards can be attained by 1981 with no transportation controls but that because of the contributions of stationary sources, aircraft and heavy duty vehicles, HC emissions never reach the allowable level.

Related Planning and Programming Activities

Two on-going Denver transportation planning activities have direct implications for air quality and should not be considered as independent efforts. These are the DOT mandated Transportation System Management Element (TSME) and Transportation Improvement Program (TIP), and the Department of Energy's State Energy Conservation Plan.

The transportation systems management element requirement calls for



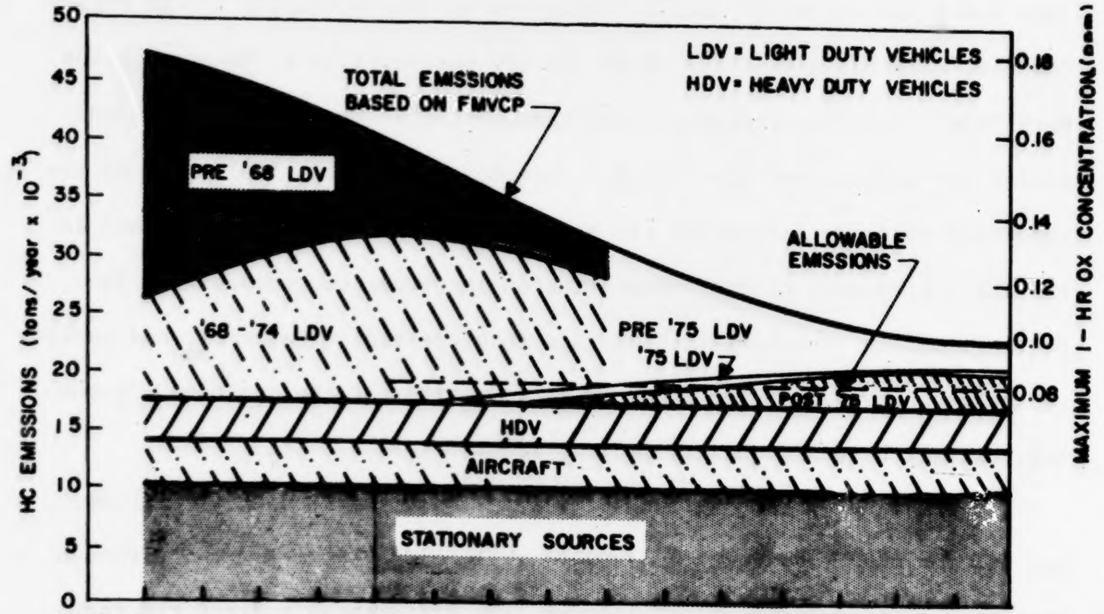


FIGURE 1-7

Source (19)

CO (Central Area) and HC Emissions by Vehicle Class and Model Year Groupings Independent of TCP Implementation urban areas to develop plans to increase the efficiency and effectiveness of their existing transportation facilities and equipment through actions not requiring new capital expenditures. The transportation improvement program is a short-range schedule of projects to be implemented, drawn from the TSME and the long range (capital) planning element. A summary of the 1976 Denver area TSM is contained in Table 1-5. A striking feature is that the plan contains measures that are identical to the VMT reduction measures in the 1973 TCP - specifically carpooling, improved transit, preferential treatment for high occupancy vehicles, parking management, and bikeway provisions. The State Energy Conservation Program provides funds to states who voluntarily develop plans of action to conserve energy. A reduction of 5% of projected 1980 energy consumption is the target. Colorado submitted its State Energy Conservation Plan to the Federal Energy Administration (now D.O.E.) in March 1977(20,21). Prepared by the Governor's Energy Policy Council, with the assistance of an "Energy Conservation in Transportation Work Team", the Plan contains eight transportation measures, eight transportation studies, and one idea for consideration (Table 1-6). Five of the committed measures and two of the studies overlap with items contained in the TCP - bikeways, public transportation improvements, carpooling, vanpooling, public transportation studies (preferential treatment), and parking surcharges. Several of the other measures, while not now contained in the TCP, clearly have air quality implications.

At the time of this writing, the TSM/TIP, Energy Conservation Plan, and TCP for the Denver area contain slightly different measures, although there is considerable overlap. In part, the differences reflect the fact that the various plans were developed through separate planning efforts with

TABLE 1-5

Denver Transportation System Management Element

(adopted 7 April 1976)

Traffic Operations Improvements

- channelization of streets/intersections
- extension of one-way street system, study of returning some couplets to two-way operation
- computerized traffic control, signalization, timing
- ramp metering freeways

Preferential Treatment to High Occupancy Vehicles

- extension of preferential lanes
- high occupancy vehicle by-pass of ramp metering and other congestion points
- exclusive bus streets as part of downtown mall
- bus pre-emption of traffic signals (longer run)

Pedestrian/Bike Provisions

Parking Management

- park/ride program continuing
- on-street parking rates have been increased; off-street rates increasing due to market forces providing de facto parking management

Reduce Peak Period

- staggered work hours
- fare incentive (10¢ less in off-peak)

Reduce Vehicle Use

- carpool program (DRCOG)

Improve Mass Transit

- marketing
- schedule coordination (local/express services)
- DRT feasibility study
- extend park and ride program

Source: (22)

TABLE 1-6

Colorado State Energy Conservation Plan

Transportation Program Measures

- Right Turn on Red
- State Bikeway Program
- Increased Enforcement of 55 Miles Per Hour Speed Limit
- Public Transportation Improvements
- Staggered Work Hours
- Four Day Work Week
- Vanpool Demonstration

Transportation Studies

- Public Utilities Commission Regulations
- Traffic Flow Improvement
- Denver Public Transportation
- Statewide Transportation Planning
- Motorcycle and Bicycle Incentives
- Parking Surcharge
- New Motor Fuels
- Highway Design, Construction and Maintenance Practices

Ideas for Consideration

- Tax/Rebates to Promote the Purchase of Fuel Efficent Automobiles differing emphasis on the objectives of transportation efficiency, energy conservation, and air quality improvement. Many of the differences already are being eliminated. For example, the consistency requirement has led to some degree of merging between the TCP and the TSME and TIP. The 1977 Clean Air Amendment's requirement for compatability between SIPs and plans and projects funded with federal dollars or approved by MPOs should accelerate the integration of the various planning processes and documents. Therefore, it is useful to examine the measures proposed in Denver's TSM, TIP, and Energy Conservation Plan, because they may be included in the transportation portion of the SIP revision to be forthcoming.

ANALYSIS FRAMEWORK

Overview

To determine the individual and combined effectiveness of the transportation measures that have been adopted to improve air quality in the Denver metropolitan area, assessments have been made of the financial investments, adminstrative support, and other commitments required for effective implementation as well as of changes in travel behavior, vehicle emissions and fuel consumption. An examination has been made of the full spectrum of implementation experience - from those measures with little or no chance of even partial implementation to those measures where implementation is essentially complete. The appraisal has been structured to:

- identify the incidence of costs and benefits, disaggregating this information so that policy makers and affected interests can assess the desirability of both individual measures and the total plan;
- examine the feasibility, acceptability and equitability of both individual measures and the plan as a whole;
- explicitly assess areas of uncertainty, stating assumptions upon which the evaluation results are based and indicating the sensitivity of the evaluation to these uncertainties and assumptions.

Figure 1-8 illustrates the analysis approach. The first step was to assess the current implementation status of each transportation/air quality measure in the promulgated TCP. Some measures already have been put into effect; some are not yet underway but have a reasonable chance of imple-

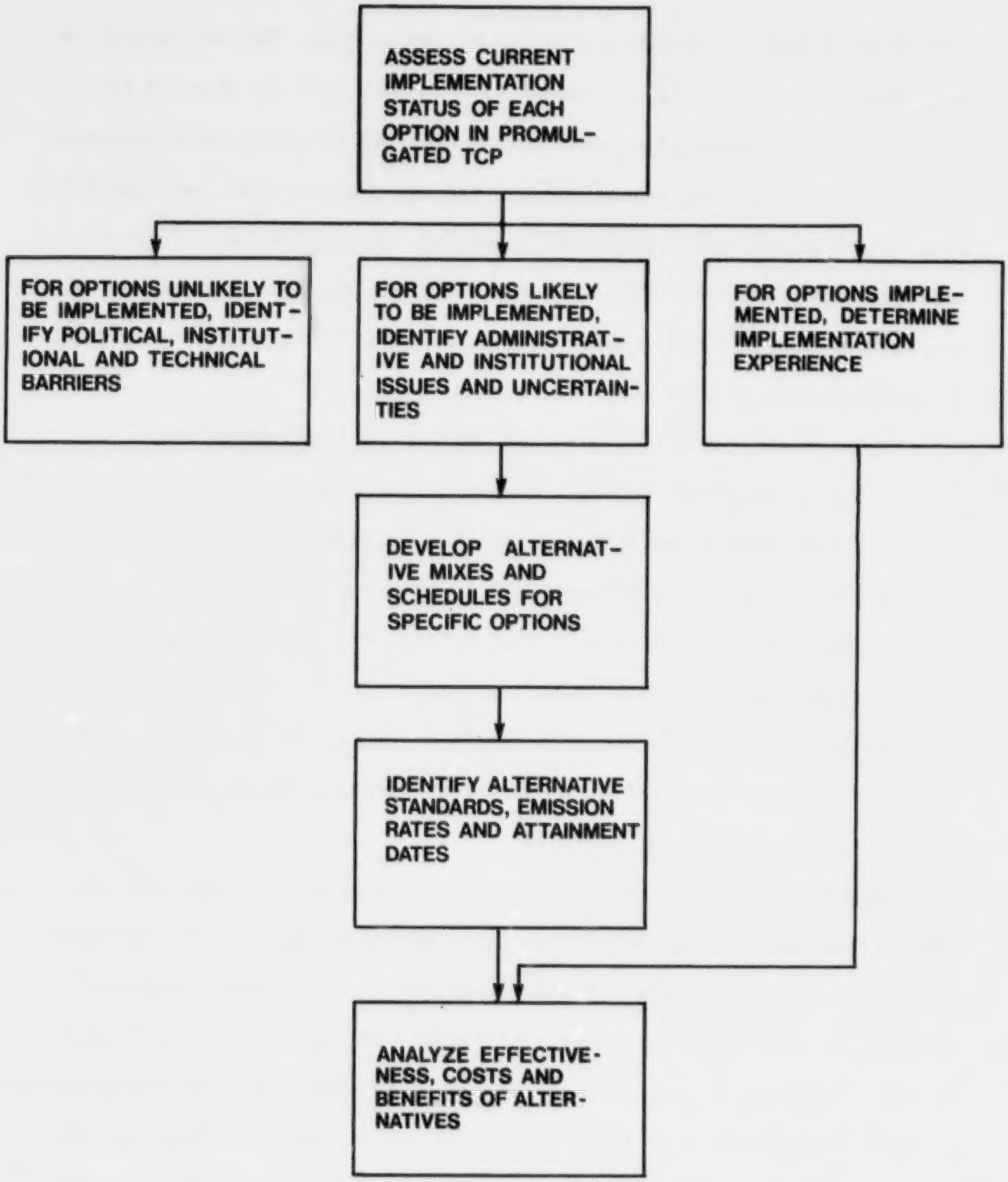

ASSESS CURRENT IMPLEMENTATION STATUS OF EACH OPTION IN PROMULGATED TCP
FOR OPTIONS UNLIKELY TO BE IMPLEMENTED, IDENTIFY POLITICAL, INSTITUTIONAL AND TECHNICAL BARRIERS
FOR OPTIONS LIKELY TO BE IMPLEMENTED, IDENTIFY ADMINISTRATIVE AND INSTITUTIONAL ISSUES AND UNCERTAINTIES
FOR OPTIONS IMPLEMENTED, DETERMINE IMPLEMENTATION EXPERIENCE
DEVELOP ALTERNATIVE MIXES AND SCHEDULES FOR SPECIFIC OPTIONS
IDENTIFY ALTERNATIVE STANDARDS, EMISSION RATES AND ATTAINMENT DATES
ANALYZE EFFECTIVENESS, COSTS AND BENEFITS OF ALTERNATIVES

FIGURE 1-8

Transportation Control Plans

mentation; others are unlikely ever to be implemented. The implementation experience for the in-place measures was examined, and the reasons for rejection of the measures in the "low probability" category were explored. For the other measures, issues and uncertainties about their implementation were investigated, and alternative schedules, strategies, and mixes of measures were developed. Then, the costs, effectiveness, and benefits of alternative measures and combinations of measures (both those implemented already and others) were analyzed.

Three basic guidelines governed the analysis approach:

- The process must be participatory. Local officials and interest groups were to be actively involved throughout the study.
- The analysis must be sensitive to the important impacts, particularly to distributional effects and the issues perceived to be important by Denver interests.
- The methodologies employed should be within the resources normally available to metropolitan and state agencies having responsibility for these kinds of analyses.

Figure 1-9 illustrates the structure of the analysis approach and provides an overview of the methodologies employed. Because the implementation of transportation/air quality measures involves both "technical" issues and "political/administrative" issues, the analysis required estimation of effects on employment, land use, auto ownership, and travel behavior as well as exploration of institutional behavior, administrative and financial issues, and political responses. The methods chosen for both parts of the analysis were selected to be usable by other states and urban areas, and the overall approach was designed to elucidate issues which are likely to arise in practically any transportation/air quality planning effort.

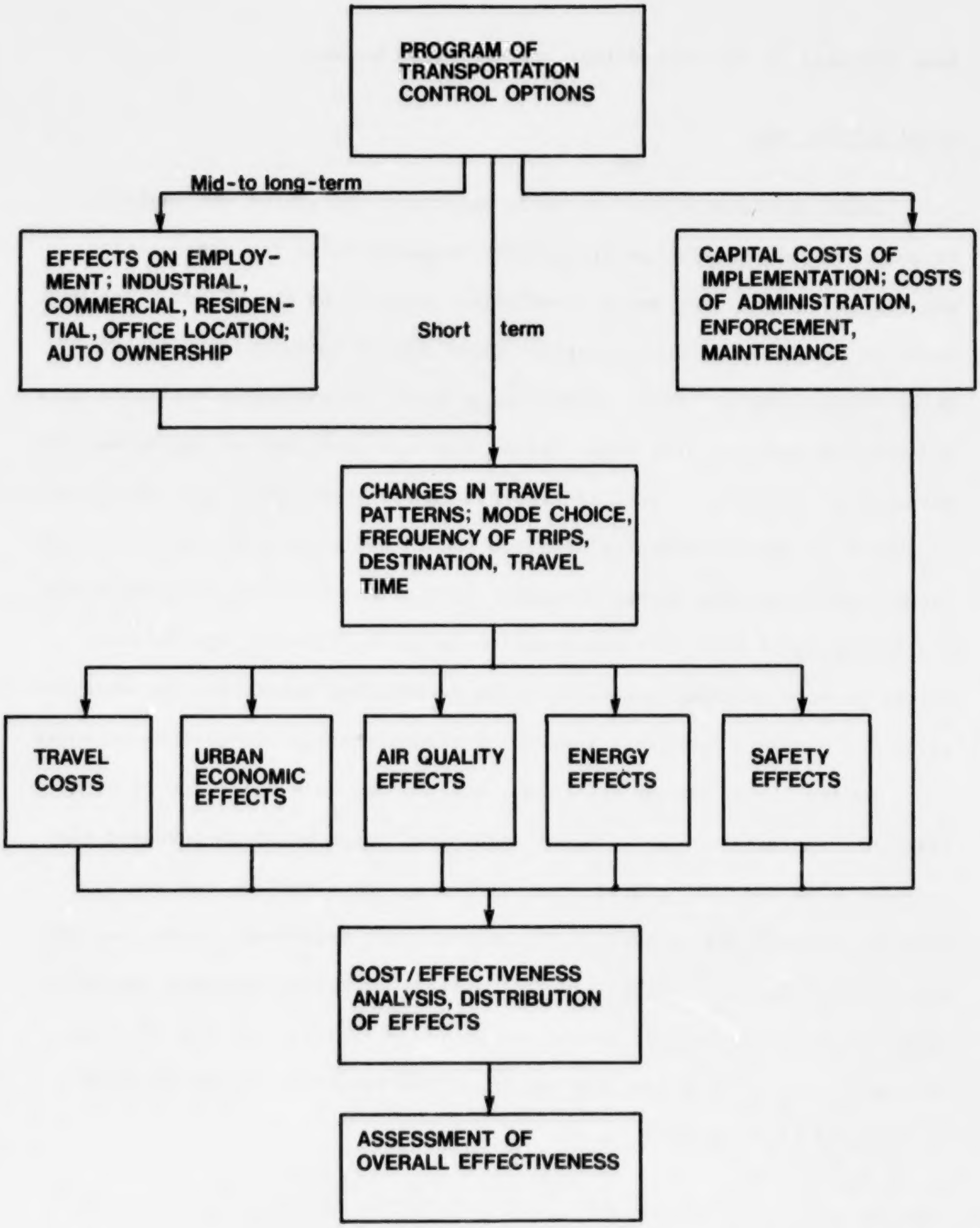

PROGRAM OF TRANSPORTATION CONTROL OPTIONS
Mid-to long-term
Short term
EFFECTS ON EMPLOYMENT; INDUSTRIAL, COMMERCIAL, RESIDENTIAL, OFFICE LOCATION; AUTO OWNERSHIP
CAPITAL COSTS OF IMPLEMENTATION; COSTS OF ADMINISTRATION, ENFORCEMENT, MAINTENANCE
CHANGES IN TRAVEL PATTERNS; MODE CHOICE, FREQUENCY OF TRIPS, DESTINATION, TRAVEL TIME
TRAVEL COSTS
URBAN ECONOMIC EFFECTS
AIR QUALITY EFFECTS
ENERGY EFFECTS
SAFETY EFFECTS
COST/EFFECTIVENESS ANALYSIS, DISTRIBUTION OF EFFECTS
ASSESSMENT OF OVERALL EFFECTIVENESS

FIGURE 1-9

Method of Approach: Cost Effectiveness Analysis

Some features of the methodology are discussed below.

Local Involvement

Local involvement was extremely important throughout the analysis, because the individuals and groups with responsibility for implementing control measures or who would be affected directly by the measures are most aware of the range of considerations which should be examined. Some of these issues are not easily identifiable simply by examining available data and reports, particularly those issues that are dependent on the values and perceptions of the concerned individuals. Local involvement was particularly important in the assessment of institutional, administrative, and political issues and in gauging agency response. It also was critical in identifying the *incidence* of impacts - who benefits or loses. Finally, the participatory process provided useful input in determining priorities for analysis, given the numerous potential impacts of transportation/air quality measures.

During the course of the study, discussions were held with 50 organizations, the majority by personal interview. These meetings involved discussions with over 130 individuals, including Mayor William McNichols; Governor Richard Lamm's appointed commissioners, department heads, and personal staff; federal officials; staff members of state, regional and local agencies; private interest groups and involved citizens. A list of these persons - each of whom has made important contributions to our findings - is provided in Appendix A.

Impacts

The range of potential impacts of transportation/air quality measures, like most transportation actions, is extremely large. Table 1-7 contains

Table 1-7

Potential Impacts of Transportation Control Plan Implementation

Transportation

- travel volumes, by trip purpose and time of day
  - modal shares
  - total users by mode
  - frequency of trips
- travel times
  - access times
  - wait times
  - line haul times
  - transfer times
- other level of service variables
  - user costs
  - safety
  - convenience
  - comfort

Economic

- retail sales, industrial, and commercial activity
- employment, by category
- land values and tax base

Environmental

- air quality
  - by pollutant
  - spatial distribution and concentrations
- energy consumption
- safety
- noise
- aesthetics

Social

- mobility and accessibility levels
- user characteristics: handicapped, elderly, auto ownership, age, income, residential location, etc.
- residential and business displacement

Institutional

- responsibilities, by agency
  - planning and design
  - implementation and operation
  - enforcement
- personnel requirements, by agency
- financial:
  - revenues
  - planning, capital, operating, and maintenance costs
  - methods of financing
  - federal, state, and local shares of costs and revenues

a partial listing of possible impact areas. In identifying and assessing these potential impacts in Denver, two factors were given particular attention.

1. The target market segment. The ability of a transportation control measure to contribute to an areawide improvement in air quality (or energy conservation) is directly related to the percentage of total Denver vehicular travel affected by the measure. For example, a measure which is directed primarily at work trip travel to Denver's central business district can reach a maximum of approximately 4% of the total daily vehicle miles of travel since work trips constitute 37% of daily travel and 11% of work trips are to the CBD. In contrast, a vehicle inspection and maintenance program affects vehicle emissions for all trip purposes over the entire region.

2. The incidence of impacts. Impacts of transportation measures may vary within the affected market segments, differing across socioeconomic groups within the population (upper income suburban residents with high automobile ownership levels may be relatively unaffected by various ride sharing incentives), across neighborhoods or other physical sub-units within the metropolitan area, and so forth. Furthermore, implementation requirements may vary across units of government, with more effort being required by some agencies and less by others. Viewed over the region as a whole, some of these impacts might not appear to be significant - for example, a set of measures which limit auto use but improve transit service may have a negligible net effect on retail sales over the entire region, while differential impacts within the region - say, between suburb and CBD - might be severe (i.e., retail sales in the CBD might drop, while undergoing an equivalent increase in the suburbs). In reviewing transportation control

plan controversies throughout the country, it is clear that much of the conflict stemmed from the perceived uneven distribution of costs and benefits among various groups which would result from implementation of those control options which could be categorized as being both auto disincentives and mandatory.

Travel Demand Behavior

Of critical importance in determining the effects - costs and benefits - to different groups and administrative units has been a basic understanding of travel demand behavior. Transportation controls are designed to increase the cost of travel of some modes (principally the drive alone auto) and either leave unchanged or lower the costs of other modes (transit, shared ride, walking, bicycling). The effect to the traveller is a change in both the actual and perceived levels of service available on different modes. Since transportation controls may apply in some areas (e.g., the central business district) and not in others (suburbs and non-urban areas), the relative attractiveness of various areas will be changed. For the worker, this may mean only a shift in his commute mode. For the person engaged in shopping, personal business, or recreation, however, it may mean a change in both the number of trips made and the choice of destination, as well as the mode of travel. These changes in travel patterns can eventually lead to changes in the location of various activities, and to changes in auto ownership levels, which in turn can lead to even further changes in travel patterns. These all contribute to changes in travel costs, air quality, energy consumption, safety and economic activity. In performing the travel behavior related analyses, special emphasis was given to utilizing previously collected Denver data and to utilizing methodologies that are consistent in approach with those now being used in Denver transportation planning. The basic data base adopted was the 1971 transportation home interview survey (23) together with transportation network and socioeconomic characteristics maintained by the Denver Regional Council of Governments, the Colorado Department of Highways, the Denver Regional Transportation District, and the City and County of Denver. Care has been given to establishing and using internally consistent information, and also to utilizing "approved" or "standard" socioeconomic projections. As in many cities, agencies have carried out several largely independent planning efforts - for transit, highways, water, land use, economic development. In several instances, differing assumptions were used in different studies - for example, different levels of future year highway or transit construction, and different levels of distribution of residential location and employment. Major attention has been devoted in Denver during the last two years to eliminating inconsistencies and, wherever possible, the agreed upon Denver "standard" has been used as the basis for our analyses rather than rederiving yet another set of estimates.

The travel behavior analyses are based on a set of disaggregate travel demand models similar in structure to the new "third generation" Denver models (24); but a broader range of socioeconomic, transportation, locational and mode specific variables are included and a more complete set of behavioral decisions are examined.[1] The models are implemented using the UMTA-FHWA Urban Transportation Planning System (UTPS) set of computer programs, the same basic package now being used in Denver (25), as well as other metropolitan areas.

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[1] The full set of travel, air quality, energy and economics methodologies utilized are described in Appendices C,D,E,F, and G.

The models predict on a household basis:

- work trip mode choice, including drive alone, public transit, shared ride auto, and vanpool alternatives, for both primary and secondary workers;
- non-work trip frequency, destination, and mode choice, differentiating between shopping or personal business trips and socio-recreational trips; and
- automobile ownership.

A sample of 1,013 households randomly selected from the Denver home interview survey was updated in terms of costs, socioeconomic characteristics, and transportation characteristics to reflect both 1975 and 1985 conditions. Then, the travel response of each household to one or more candidate transportation measures was "simulated" probabilistically by sequentially proceeding through the individual demand models. These predictions at the individual household level permitted stratification of areawide travel impacts according to household socioeconomic and geographic characteristics such as income level, residential location, and automobile ownership.

This travel demand information was of central importance to the identification of transportation controls' costs and effectiveness. For example, the estimation of safety effects requires the number of passenger-miles travelled on each mode and on each mode and on each route; fuel consumption is related to vehicle type and age, vehicle weight and occupancy, trip length, cold or hot start, travel speed, and degree of congestion. Similarly, determination of changes in retail sales requires information on changes in basic travel patterns such as the number of shopping trips made and the choice of destination.

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CHAPTER 2

INSTITUTIONAL RESPONSIBILITIES

INTRODUCTION

In many urban areas, the transportation control plans of the 1973-1977 period were developed primarily by state air quality agencies and the U.S. Environmental Protection Agency. Yet for most of the measures, responsibility for detailed planning and for implementation resides with a number of local, regional and other state agencies, some of which had little direct involvement in the selection of the TCP measures. This is the case in Denver, where EPA and the Colorado Air Pollution Control Commission played the major roles in developing the promulgated TCP, but the Denver Regional Council of Governments, the Regional Transportation District, the Colorado Department of Highways, and several city agencies are charged with carrying out most of the activities necessary to implement the plan.

This chapter reviews the Denver area's institutional arrangements, assignments of responsibilities, and recent experiences as they affect the prospect for implementation of transportation/air quality improvement measures. The next section provides a framework for the analysis. Subsequent sections present information on the agencies which have had significant involvement in transportation and air quality activities in the Denver metropolitan area and examine the roles of several private interest groups in Denver transportation air quality planning.

DETERMINANTS OF AGENCY RESPONSIVENESS

To assist in understanding the responses of individual agencies in the planning and implementation of particular control plan measures, a framework encompassing certain program measure characteristics was employed:

- degree of public and private cost;
- nature of compliance: voluntary or mandatory;
- perception of program necessity;
- level of symbolic benefits;
- degree to which accountability is diffused or centralized.

The acceptability of a particular measure to both the public and an agency in large part reflects an assessment of these characteristics, although these factors are not always consciously or explicitly specified. For example, the most desirable situation is when program benefits are obvious, costs are low, and compliance is voluntary. Examples of such "incentives" are carpool promotion and bicycle lanes. Acceptability is lowered if the necessity for the program is not widely perceived, if compliance becomes mandatory, or if enforcement, penalties or other disincentives become necessary. Parking restrictions usually fall in this latter category.

Programs may be undertaken by an agency even though their areawide effectiveness may not be high, because of their high visibility, their ability to contribute to an increased awareness of an issue such as the need for air quality improvement or energy conservation, and their positive "symbolic" association with such issues. The bicycling promotion component of a TCP can be considered as being in this category. Transit, at least at the national level, also is considered by some as being of primarily symbolic value as far as air quality and energy benefits are concerned, although meaningful benefits may be obtained within well defined areas through specific actions.

Program measures involving significant public or agency costs generally are less popular, especially when the benefits are not readily apparent. The measures' acceptability from an agency perspective, however, may be increased to the degree that their costs or accountability for them can be diffused among several agencies or organizations. Colorado's recently legislated vehicle inspection/maintenance program is of this type since consumer costs for inspection and maintenance are charged by private inspection stations rather than by APCD itself.

As a final example, a program measure for which there is a high public or agency cost, the necessity for the disincentives is not readily apparent or accepted, and the "blame" easily can be directed towards the implementing agency will be least acceptable from that agency's perspective. If such programs are implemented, significant and effective public resistance can be expected.

Just as program measures can be described in terms of certain generic characteristics, agencies also have characteristics which may either facilitate or impede effective planning and implementation. They include:

- degree of traditional agency experience with or commitment to the program measure;
- ability to generate support for implementation;
- visibility with the electorate;
- accountability to the electorate;
- interrelationships with other agencies.

The degree of agency experience with or commitment to a program measure is a central determinant of agency response and is particularly relevant in considering transportation/air quality measures, since such measures rarely have a "track record." In some situations, an agency may have the legal authority or responsibility for a particular program, but either because the program is of low priority within the agency or because it does not correspond to traditional agency activities, the agency's involvement or commitment to implementation is minimal. Low commitment also may result when planning occurs in one agency but implementation responsibility falls to another; the implementation agency may not have a high desire to carry out decisions made by others.

Even when an agency is strongly committed to an action, it may lack the funding, staff, or authority necessary to carry it out. An agency with responsibility primarily for planning may be unable to achieve the degree of cooperation or interest necessary among other agencies to achieve effective implementation. Metropolitan planning organizations often fall into this category since they frequently lack the authority to implement many types of projects.

An agency's ability and desire to implement innovative measures also is affected by its visibility among citizens and private interest groups (that is, how well known it is and the extent to which its actions are recognized as its own) and its accountability to elected officials or the electorate. An agency of both high visibility and accountability, such as a Mayor's Office, normally will be careful about experimenting with actions that are non-traditional or have uncertain consequences, especially if there is a chance that those actions may prove to be less than universally popular. Conversely, an agency which is not well known among citizens and interest groups and which does not have direct ties to the electorate may find it easier to take "risky" or controversial actions (such as disincentives to auto use), at least partially because it is less likely that such an agency would experience direct repercussions from implementation. State health and highway departments might be placed in this category. Even so, a traditionally low visibility agency may find that it has become both more visible and more subject to political pressures as it gets involved in controversial programs. This is especially true if there are few other agencies involved, so that there is little diffusion of accountability for the programs.

Finally, the interrelationships among the various governmental agencies having an involvement in transportation are determinants of the chances of implementation. In most urban areas, a delicate balance of "territory" has been achieved between highway and transit agencies and among federal, state, regional and local agencies. Traditional measures normally are processed without difficulty, with agencies generally following routine procedures and taking predictable postures. Innovative measures may threaten to alter the balance among agencies, and in so doing, may become controversial and encounter significant resistance to implementation.

In Denver over eight agencies have major implementation responsibilities of various sorts, and achieving a consensus among them or even among an affected subset can be a sizeable task. EPA, UMTA, the Federal Highway Administration (FHWA), and the Colorado Department of Health are relatively low visibility agencies and are relatively insulated from public reaction.

DRCOG, as a planning agency, is not especially visible, and although its policy board is responsive to public reaction, the COG itself can only indirectly be held accountable for its actions. In contrast, RTD is highly visible, and although it is not immediately accountable to the public, RTD strives to maintain good rapport with the electorate because voter approval is necessary to maintain the transit agency's real estate and sales taxing authorities. The Denver City and County agencies - Public Works, the Planning Office, and the Police Department - are not only highly visible, but they report directly to elected officials who feel the full force of public opinion and transmit it on to the agencies.

An example illustrates how program and agency characteristics interact and affect implementation. Preferential treatment facilities normally not only act as an incentive to ride sharing but also require enforcement and disincentives to driving alone. Faced with proposals for preferential treatment on several Denver facilities, the various Denver area agencies reacted much as one might expect. The federal agencies and the Department of Health promoted the concept; DRCOG generally (if unenthusiastically) supported the proposals; RTD, with direct responsibilities for preferential treatment facility operations, moved with caution; and the city agencies, who have been hesitant to support any measure which might be construed as a disincentive to automobile use and who have responsibility for enforcing the lanes even though violations may be confused with turning movements, have only reluctantly gone along with the preferential lanes and have given them relatively low priority.

INSTITUTIONAL SETTING

Over the past few years, several highly controversial events occurred within the Denver metropolitan area which precipitated major changes in regional activities and institutional arrangements. Four events which were of particular importance are:

- Rejection in 1976 by the Governor of the Colorado Department of Highways proposal to construct I-470 as a circumferential highway in the southwest sector of suburban Denver. A subsequent restudy has resulted in a decision to proceed with a limited access parkway in roughly the same corridor.
- Rejection in 1976 by the DOT's Urban Mass Transportation Administration of Denver's light rail transit application.
- Conditional certification in 1976 by FHWA and UMTA of Denver's urban transportation planning process. Factors cited were the lack of an air quality analysis and definitive determination on the consistency of the region'a air quality and transportation plans (i.e., the 23 USC 109(j) consistency determination) and the lack of sufficient input by local public officials.
- Redesignation in 1977 of the designated metropolitan planning organization (MPO) from the Joint Regional Planning Program (JRPP) - an equal partnership of CDH, RTD, and DRCOG - to DRCOG.

The outcomes of these events demonstrated that the region's transportation and land use plans (adopted in 1973 by the JRPP, the designated MPO at that time) were seriously outdated and, in addition, highlighted coordination problems between regional and state agencies involved in transportation and air quality activities for the Denver area. Currently, regional and state agencies, in particular DRCOG (as the newly designated MPO) are in the midst of a Transportation Plan Restatement Process. Concurrently with this activity, the Department of Health's Air Pollution Control Commission (APCC) and Air Pollution Control Division (APCD) as the state's air quality agency are developing revisions to the Colorado Air Quality State Implementation Plan (SIP). Common objectives of DRCOG and APCC/

APCD are that the revisions of the transportation, land use and air quality plans are developed in such a way that the results are realistically workable, and consistent with each other. To accomplish this objective, the air quality and transportation agencies are attempting to improve the level of coordination that exists within the region. However, it is still too early to assess the effectiveness of this renewed effort of interagency coordination and the degree of change which will actually occur. The institutional environment which preceded the region's current efforts will continue to have an important influence on Denver transportation developments and has largely determined the experience to date in implementing Denver's Transportation Control Plan.

Colorado Department of Health

Two groups in the State of Colorado have important air quality responsibilities for the Denver area:

- The Air Pollution Control Commission is a policy body appointed by the Governor.
- The Air Pollution Control Division of the Colorado Department of Health provides technical support to the Commission.

The working relationship between these two groups has been an important determinant of air quality related transportation policy in the Denver region.

The Air Pollution Control Commission (APCC) was created by the Air Pollution Control Act of 1970.[1] Each of the nine members is appointed by the governor and confirmed by the Senate; the ninth member is designated by the State Board of Health and appointed by the governor. Although members are not required to have any specific qualifications, some of the current members have previous experience in air quality issues. The APCC functions as a quasi-independent body within the Department of Health (DOH) to set state air quality policies in conformance with their mandate specified in the 1970 legislation which prescribes the following key responsibilities:

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[1] Section 25-7-104.

- to develop and maintain a comprehensive program for prevention, control, and abatement of air pollution, including an emissions control program and promulgation of ambient air goals for every portion of the state;
- to promulgate emission control regulations which require the use of effective practical air pollution controls for each pollutant;
- to promulgate regulations that are necessary or desirable for carrying out the Commission's legislative mandate.

To assist the Commission in carrying out its tasks, the Air Pollution Control Division (APCD) was created by the Act to provide technical support for the APCC.[1] The APCD has 75 employees in its four sections: Air Quality Surveillance, Mobile Sources, Stationary Sources, and Planning and Analysis. Figure 2-1 illustrates the APCD's organizational structure and the broad responsibilities of the four sections within the APCD. Three of the sections have transportation related responsibilities: Mobile Sources is responsible for the vehicle control program; Stationary Sources has enforcement responsibilities for the Regulation 9 Carpooling Program;[2] and Planning and Analysis has responsibilities for the preparation of the State Implementation Plan (SIP) and in the air quality consistency assessment.

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[1] Section 25-7-110.

[2] Stationary Sources was the only section having any enforcement responsibilities for other APCD programs and thus, because of their enforcement experience, were designated to enforce the carpool program.

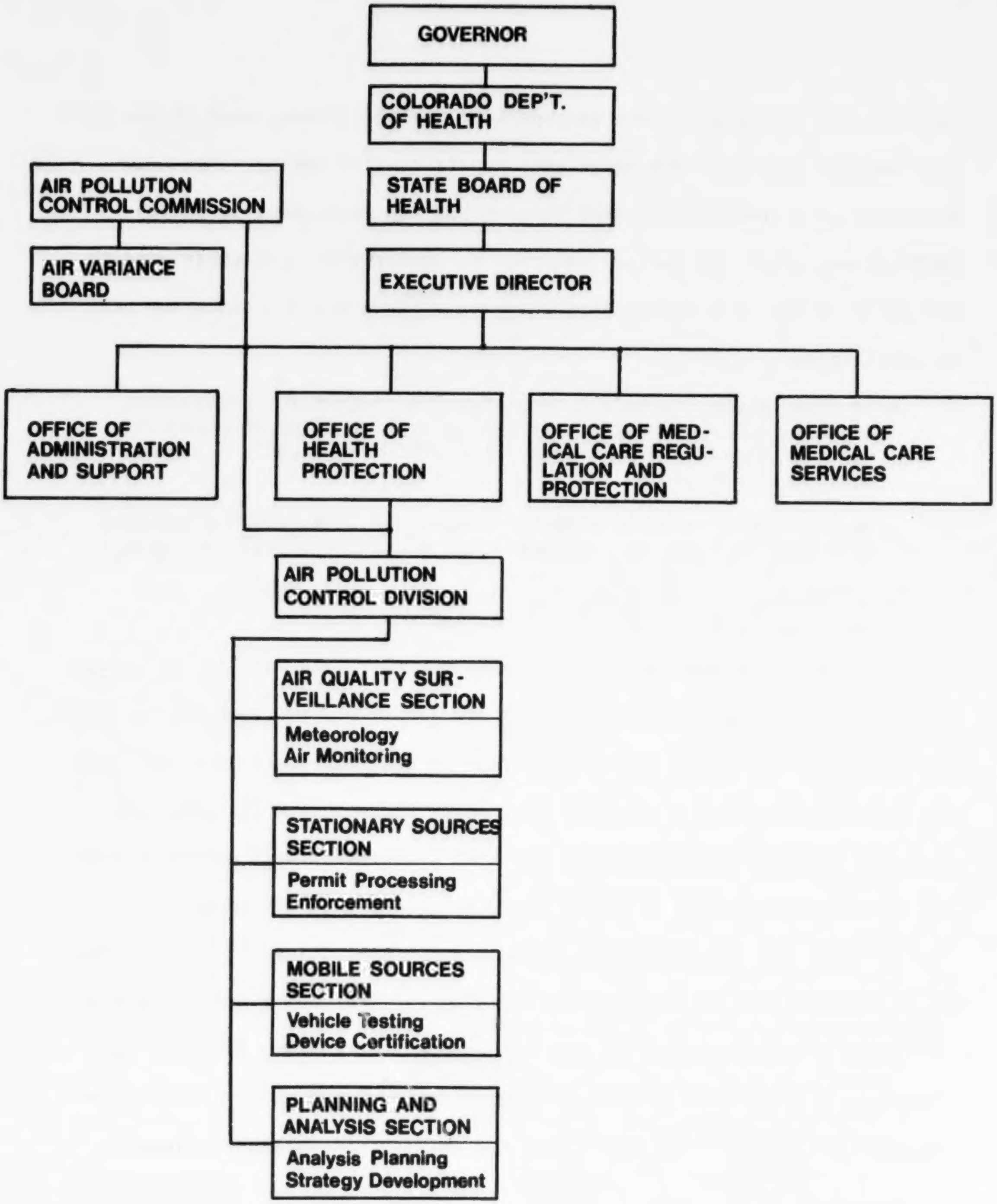
GOVERNOR
COLORADO DEP'T. OF HEALTH
STATE BOARD OF HEALTH
AIR POLLUTION CONTROL COMMISSION
AIR VARIANCE BOARD
EXECUTIVE DIRECTOR
OFFICE OF ADMINISTRATION AND SUPPORT
OFFICE OF HEALTH PROTECTION
OFFICE OF MEDICAL CARE REGULATION AND PROTECTION
OFFICE OF MEDICAL CARE SERVICES
AIR POLLUTION CONTROL DIVISION
AIR QUALITY SURVEILLANCE SECTION
Meteorology
Air Monitoring
STATIONARY SOURCES SECTION
Permit Processing
Enforcement
MOBILE SOURCES SECTION
Vehicle Testing
Device Certification
PLANNING AND ANALYSIS SECTION
Analysis Planning
Strategy Development

FIGURE 2-1

Colorado Department of Health - Organization Chart

The APCD had a 1976 budget of just over $2,000,000, provided in approximately equal portions from EPA, the state general fund, and motor vehicle safety inspection fees. Approximately 25% of this budget was spent for transportation and mobile sources related activities, with roughly $50,000 being used for air quality maintenance planning, $10,000 for Section 109(j) transportation/air quality consistency analyses, and $15,000 for work related to Regulation No. 9. A minimum of 60% of the transportation and mobile sources budget has been spent each year for activities related to vehicle inspection and maintenance.

Since the APCC's creation, it has steadily increased in visibility in the air quality activities of the State of Colorado. During the process, the APCC has had victories and losses, and its position today with regard to transportation related air quality issues is still evolving. Many of the difficulties the APCC has experienced can be attributed to two primary factors. First, in accordance with its legislative mandate, APCC has affected agency interrelationships by exercising its responsibilities for specification of transportation programs. Previously, these would have fallen exclusively within the JRPP structure of RTD, DRCOG and CDH. Second, the APCC's involvement in several controversial and highly visible transportation issues affected the credibility of both the APCC and the APCD. These issues include specific transportation projects, state legislation, and staff qualifications and conflicts within the APCD.

Specific examples of APCC and APCD activity are discussed below.

The Promulgation of APCC Regulation No. 9

Regulation 9, presented in Appendix B to this report, was promulgated by the APCC to address the measures contained in Denver's TCP. The regulation calls for action on transportation measures and studies which are the responsibilities of other agencies and therefore require their cooperation. DRCOG and RTD, in cooperation with CDH and other agencies, are required to conduct studies on such measures as parking management and to set up programs to encourage transit use and ridesharing.

The APCC and APCD role in the preparation of air quality plans and vehicle emission controls is recognized, although not always liked, by other agencies. In the areas of public transportation and ridesharing, however, APCC and APCD involvement is seen as potentially impinging on RTD, DRCOG and CDH responsibilities. The transportation agencies also have questioned APCC/APCD involvement in transportation activities because APCD has few transportation specialists on its staff.[1] In addition, the transportation agencies have been concerned that the measures and studies included in Regulation 9 were only minimally coordinated with the formal transportation planning process conducted by DRCOG, RTD, and CDH. As a result, there has been some reluctance on the part of these agencies to carry out the regulation.

The Air Quality Consistency Controversy

In accordance with the provisions of Section 109(j) of Title 23 U.S.C., FHWA must review the MPO's planning process and its assessment of whether any serious inconsistencies with SIP requirements exist. FHWA regulations also require evidence that coordination is occurring between the air quality agencies and the transportation agencies. In January of 1976, the JRPP concluded, with limited technical analysis, that its transportation plans and programs were consistent with the SIP. However, after consulting with EPA, FHWA responded that until a complete consistency analysis was carried out, a definitive consistency determination could not be made. In addition, the APCC, which had participated in the preparation of the limited air quality analysis performed by JRPP, contended that no real coordination had occurred and also claimed that the JRPP consistency assessment was not in compliance with the consistency criteria contained in joint EPA/FHWA guidelines (1).

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[1] For example, the Mobile Sources section of the APCD does not have any designated transportation planners on their staff.

FHWA and UMTA also were dissatisfied with the JRPP designation as MPO because it resulted in rather indirect decision authority for locally elected officials, who are given such authority in the metropolitan transportation planning process under federal law (2). Because of these problems (and certain others), during the Fall of 1976, FHWA and UMTA issued a conditional certification of the transportation planning process with regard to FHWA funding. (Full UMTA funding was retained.) The conditional FHWA certification limited further program approvals to safety and transportation systems management projects. This was of particular concern to DRCOG and CDH, whose activities were in part funded by FHWA money.

After redesignation by the Governor of DRCOG as the MPO,[1] long and heated debates, and pressure by the affected agencies to restore certification, FHWA reinstated full funding in March 1977, based on the transportation agencies' efforts to resolve the problems cited by FHWA and others and on efforts to improve agency coordination.

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[1] DRCOG was designated as the MPO in January, 1977, thus replacing JRPP after a long struggle by DRCOG. This is discussed further in the section on DRCOG.

During the certification negotiations, APCC requested representation on DRCOG's policy and transportation committees. They were granted non-voting membership as one of the state's three representatives on DRCOG's policy committee and a voting membership on two technical committees, the Transportation Advisory Committee and the Regional Review Team. In return, DRCOG was "invited" to participate in all APCC meetings involving transportation matters.

All agencies involved are continuing discussions to decide how the Denver region can improve the interface between transportation and air quality planning. Although the consistency issue led to concessions for both DRCOG and APCC, it has increased APCC's involvement in Denver's transportation planning activities.

Developing an Inspection and Maintenance Program

The APCC and APCD efforts to obtain legislation authorizing a vehicle inspection and maintenance program (I/M) provide examples of the internal problems experienced by APCD and the effect that these have had on the credibility of both the APCD and the APCC.

In early 1975, the then director of APCD presented to the legislature (whose authorization was required for I/M), projections of benefits attributable to the proposed I/M program. Subsequently, the accuracy of these benefits were questioned by the media, encouraged in part by at least one key member of the APCD staff. It was claimed that the I/M benefits cited by the APCD director were overestimations due to the use of incomplete data and misleading terminology. Although this discrepancy was later resolved, the incident did receive much publicity and provided opponents of the I/M program, as well as of APCD and APCC in general, with opportunities to raise questions about the qualifications of the APCD director. As a result of this controversy and a similar controversy over I-470,[1] the director of the APCD was eventually forced to resign, which lowered the credibility of APCD and APCC.

The above events contributed to the state legislature's scepticism of the APCC's entire program; and,when in May, 1977, the Senate rejected one of the Governor's appointees to the APCC, this was viewed by many as an indication of the Senate's dissatisfaction with the APCC.[2] A bill passed by the legislature in 1978 shifted all responsibility for the I/M program from the APCC to the Department of Revenue, but this was vetoed by the Governor and the veto was subsequently upheld by the legislature.

Two other issues further hurt the image of APCC and APCD. The first involved a difference of opinion between the Mobile Sources and Stationary Sources divisions of the APCD over the appropriation of APCD's portion of the safety inspection fee. Thirty cents of the automobile safety inspection fee,which generates approximately $600,000 per year, is placed into a special account in the highway fund for the "activities" of APCD's Mobile Sources section. The Stationary Sources section felt that they should be entitled to the use of a portion of these funds to carry out their Regulation 9 responsibilities relating to mobile sources. This feeling is strengthened by the existence of a $1.2 million surplus in this account.

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[1] The APCD executive director opposed I-470, citing adverse air quality impacts, although the APCD staff refuted this claim in testimony before a legislative committee. CDH, the auto service industry, construction firms and trucking associations were very upset over the executive director's stand on I-470 and this may in part explain some of the subsequent opposition to the I/M program from some of these groups.

[2] This rejection also reflected the strained relations between the Senate and the Governor; the Senate majority is not of the Governor's party.

The second issue which further complicated matters was the contention by some service industry representatives that the $.30 funds were being used for salaries of members who were not involved in activities covered by the $.30 funds. This issue was resolved in June, 1977, when after much debate and lobbying, an I/M program was approved by the Legislature containing a provision restricting the use of $.30 funds to "cover the cost of the motor vehicle emission control studies and training programs and administration thereof."

It appears that both the APCC's promulgation of Regulation No. 9 and the air quality consistency controversy have been instrumental in increasing APCC's influence and visibility in Denver's transportation planning activities. However, their effectiveness in this increased transportation role has not been helped by the problems both the APCC and the APCD have experienced during the development of a vehicle inspection and maintenance program.

Denver Regional Council of Governments

The Denver Regional Council of Governments (DRCOG) encompasses Adams, Arapahoe, Boulder, Clear Creek, Douglas, Gilpin and Jefferson Counties and the City and County of Denver. It is the designated MPO and A-95 review agency for Colorado's State Planning Region 3. DRCOG is governed by a Policy Council made up of elected officials from each of the member municipalities and counties in the region. Three nonvoting state members appointed by the Governor also are members of the Council. The organization of DRCOG's staff is illustrated in Figure 2-2. The staff provides research assistance to the Policy Council and its various specialized committees.

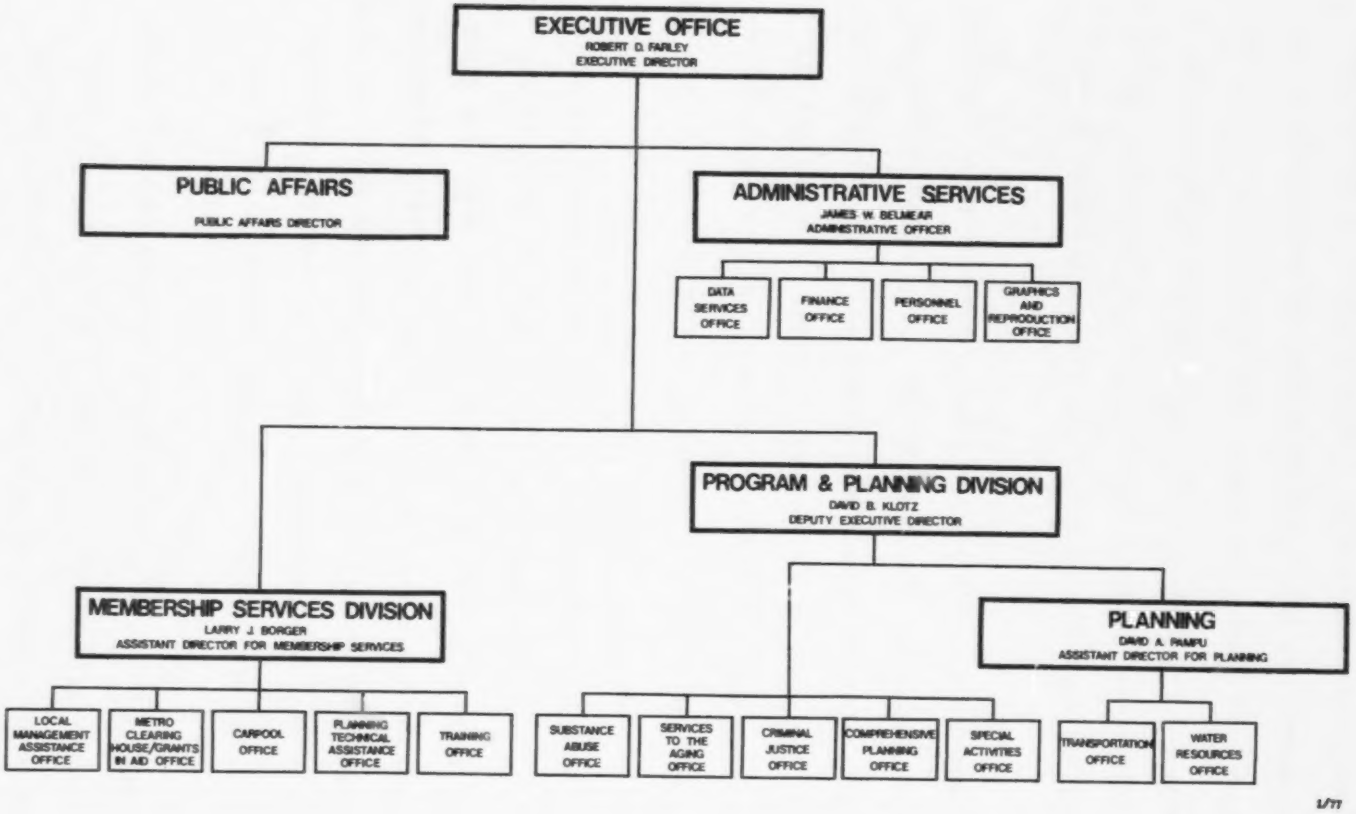
EXECUTIVE OFFICE
ROBERT D. FARLEY
EXECUTIVE DIRECTOR
PUBLIC AFFAIRS
PUBLIC AFFAIRS DIRECTOR
ADMINISTRATIVE SERVICES
JAMES W. BELMEAR
ADMINISTRATIVE OFFICER
DATA SERVICES OFFICE
FINANCE OFFICE
PERSONNEL OFFICE
GRAPHICS AND REPRODUCTION OFFICE
PROGRAM & PLANNING DIVISION
DAVID B. KLOTZ
DEPUTY EXECUTIVE DIRECTOR
MEMBERSHIP SERVICES DIVISION
LARRY J. BORGER
ASSISTANT DIRECTOR FOR MEMBERSHIP SERVICES
LOCAL MANAGEMENT ASSISTANCE OFFICE
METRO CLEARING HOUSE/GRANTS IN AID OFFICE
CARPOOL OFFICE
PLANNING TECHNICAL ASSISTANCE OFFICE
TRAINING OFFICE
PLANNING
DAVID A. PAMPU
ASSISTANT DIRECTOR FOR PLANNING
SUBSTANCE ABUSE OFFICE
SERVICES TO THE AGING OFFICE
CRIMINAL JUSTICE OFFICE
COMPREHENSIVE PLANNING OFFICE
SPECIAL ACTIVITIES OFFICE
TRANSPORTATION OFFICE
WATER RESOURCES OFFICE
1/77

FIGURE 2-2

Staff Organization

Denver Regional Council of Governments

DRCOG is involved in the development of regional plans in transportation, land use, air quality and water quality and in the development of regionwide population and employment forecasts. Most of COG's activities consist of such planning and providing certain grant administration services for its member jurisdictions, although DRCOG has been given partial implementation responsibility for Denver's carpool program as mandated in APCC Regulation 9.

All jurisdictions are eligible to join DRCOG. Membership is voluntary; it is nonetheless beneficial for the jurisdictions to belong to the organization since federal procedures channel many grants and other funds through DRCOG. However, the interests of the current 37 member jurisdictions are diversified, which often makes if difficult for the Council to achieve consensus. The policies that are adopted generally are moderate since majority support is required for approval. For instance, the continued membership of the City of Denver is important to COG, and this gives Denver significant influence on the types of actions that COG pursues which may affect the City. Although Regulation 9 requires DRCOG to conduct a parking study and to recommend parking approaches that could stimulate public transportation and reduce single passenger VMT, the City of Denver has been reluctant to pursue this course of action, and consequently, DRCOG did not begin the study until it became an issue tied to continued federal certification of the planning process.

As another example, DRCOG is responsible for deriving regional population forecasts. However, the jurisdictions also develop their own forecasts and there often are discrepancies between COG's projection and the jurisdiction's estimates. When Jefferson County proposed to withdraw from

COG unless COG accepted the locally developed forecasts, COG agreed to this change and adopted a policy which they hope can resolve differences of this nature in the future. Basically, DRCOG will use the local jurisdictions' estimates if no more than a 15% or 6,000 person difference exists. When greater discrepancies arise, COG will review the local estimates and, in cases where the differences cannot be resolved, the matter will be referred to the Policy Council for a decision.

Table 2-1 shows the allocation of DRCOG's 1976 budget by functional category. Of the total $3.378 million budget, $640,000 was earmarked as pass through funds to local jurisdictions from the federal government. Of the remainder, $659,000 (24%) was allocated to transportation planning and $106,300 (4%) to the DRCOG carpooling program. $360,000 (56%) of the pass through funds were used for technical transportation studies. In total, 33% of the total budget was allocated specifically to transportation activities.

DRCOG does not have the authority to levy funds; it is dependent on federal and state allocations, which can vary from year to year, and on the dues collected from member agencies. However, as the MPO and A-95 agency, DRCOG can exert some infleunce through its allocation of federal funds to member jurisdictions. Although allocation of earmarked federal funds (such as the Urban Systems funds) is strictly administrative, the ability to use discretion in allocating grants and pass-through funds presents an opportunity to strengthen COG's say about planning efforts. For example, since COG has ultimate responsibilty for Unified Work Program application approvals and grant allocation, it is theoretically able to influence the types of tasks which will be pursued by the grant recipients. In reality,

TABLE 2-1

DRCOG's 1976 Budget by Program Category

General Operating Fund	1976 Budget	
Transportation Planning	$659,900	
Water Resources	625,000	
General Planning & Management	522,200	
Carpooling	106,300	
Other[1]	824,600	
Total General Operating Funds		$2,738,000
Pass-Through Funds		
Technical Transportation Studies	$360,000	
Aging Program	270,000	
Local Planning Assistance	10,000	
Total Pass-Through Funds		640,000
Total General Operating & Pass-Through		$3,378,000

Source: (3)

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[1] This is comprised of six other program categories, none being greater than $216,000.

however, this impact is lessened since both CDH and RTD have an important voice in the final decision.

MPO Designation

Prior to January 1, 1977, the MPO was a triumvirate of three regional agencies: DRCOG, RTD, and CDH. These three agencies were signatories to a Memorandum of Agreement[1] which formed the Joint Regional Planning Program (JRPP) to carry out "the continuing, cooperative, comprehensive" transportation planning process for the Denver metropolitan area. While the JRPP designated DRCOG as the Policy Body on behalf of the JRPP organization, DRCOG could only ratify those items which received unanimous consent of the "Regional Director," which was the Executive Directors of DRCOG, CDH and RTD. Thus, the DRCOG Policy Council had no independent authority to make decisions and was dependent on the CDH and RTD, both of which were transportation operating agencies. FHWA and UMTA felt that this structure might not give local officials the desired control and authority, and because of this, they felt that JRPP's compliance with federal regulations was questionable.

DRCOG had long been interested in being the designated MPO for the region and felt that COG designation would be consistent with the intended purposes of MPO's. The events during 1976 concerning the adequacy of JRPP's air quality analysis and consistency assessment and the FHWA/UMTA conditional certification contributed to an increasing disfavor of the three-party JRPP structure.[2,3] After long and involved debates, DRCOG was designated as the MPO effective January 1, 1977.

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[1] The Memorandum of Agreement was signed on April 16, 1971, and amended on June 28, 1974 and February 3, 1976.

[2] The air quality consistency controversy is discussed in greater detail in the discussion of the APCC and APCD.

[3] Certification was restored in March, 1977, after the transportation agencies demonstrated efforts to resolve the problems.

RTD and CDH continue to be represented with DRCOG on the Transportation Committee; RTD and CDH each have three representatives, and DRCOG has four representatives. RTD and CDH no longer have virtual control over the Policy Council as they did in the previous arrangement; but in actuality, the relative influence of the two agencies may not have been significantly affected. Although RTD and CDH receive some federal funds through DRCOG, the pass through of these funds is fairly consistent with the plans proposed by each of the agencies. Also, both RTD and CDH have independent funding sources, and both are operating and implementation agencies with significant authority and independence in designing their plans and programs. Their continuing influence is formally recognized in the most recent Memorandum of Agreement, which notes that, although the MPO is responsible for meeting federal and state planning requirements, RTD and CDH involvement and cooperation are necessary to assure implementation feasibility.

Regional Transportation District

The Regional Transportation District (RTD) was created by the Colorado legislature in 1969,[1] after extensive lobbying by Denver area officials and private interest groups. The RTD service area includes the City and County of Denver, Boulder and Jefferson Counties, the western portion of Adams and Arapahoe Counties, and the northeast portion of Douglas County.

RTD is governed by a 21-member Board of Directors, each of whom serves a four-year term. Ten directors from the City and County of Denver are appointed by the Mayor and confirmed by the City Council. Adams, Arapahoe, Boulder, and Jefferson Counties' two representatives each and Douglas County's one representative are appointed by their respective County Commissioners and are approved by a majority of the governing bodies from the municipalities that are included within the District. The final two directors are selected by the other 19 members of the Board.

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[1] CRS 1973, 32-9-101.

The Board of Directors is legally required to approve all of RTD's operations, although in practice the Board is highly influenced by RTD's strong Executive Director. Major policy directions usually originate within RTD and then are presented to the Board for approval.

RTD's enabling legislation mandated the District to develop a comprehensive transit plan for the Denver area. To a large extent this has accounted for the broad discretion that RTD has had over transit development plans, programs and actions for the region since its creation. The transit element of the regional plan is developed by RTD and given to DRCOG who, for the most part, incorporates it into the plan as submitted.

RTD also can afford this level of autonomy because it has exceptional financial and operating independence included in its enabling legislation. RTD is authorized to levy up to two mills on each dollar assessed property valuation within the District for the payment of any annual deficit in operations and maintenance expenses, as well as up to one-half mill on each dollar of assessed valuation for payment of all other expenses. In addition, RTD has the authority to levy a 1/2% sales tax to provide revenue to finance RTD operations, to defray the cost of construction of capital improvements and acquisition of capital equipment, and to pay interest and principal on the District's securities. They exercised this authority in 1973, at which time the District voters approved a 1/2% sales tax to finance up to $425 million in revenue bonds. A substantial number of federal grants and loans also have strengthened RTD's position.

In 1976, $44 million of RTD's total $84,224.534 budget was allocated to capital expansion, with $29 million going to bus transit operations and the remainder to systems development, planning and administration (4). Federal grants comprised 37% of the budget, the 1/2% sales tax generated 31%, fares contributed 11% of the total (but 31% of bus operations) and the two property taxes generated 8%. The remaining 13% was accrued funds from the previous year and income from investments.

Rail Transit Proposals[1]

Since its creation, RTD has pursued funding for a rail rapid transit system. The initial plan proposed by RTD was for Personal Rapid Transit (PRT), which was considered to be compatible with Denver's low density land use pattern. A demonstration project sponsored by UMTA helped to popularize the concept, and PRT as a general form of transit improvement enjoyed broad (though not universal) support among private interest groups and affected jurisdictions.

In September, 1973, 57% of the voters approved a question authorizing a 1/2% sales tax for transit.[2] After this referendum, the RTD asked UMTA for financial assistance to further PRT development. However, UMTA required the District to conduct a full scale alternatives analysis. In 1975, RTD submitted a grant application to UMTA for a 28-mile segment of an 80-mile automated rapid transit system (ART) plus expanded bus service, which they hoped would be less technologically risky, less expensive, and thus more acceptable to UMTA. RTD later revised this proposal to a 22-mile light rail system (LRT) in response to questions UMTA had regarding the ART proposal. In June, 1976, UMTA rejected Denver's light rail proposal on the grounds that bus improvements would provide equivalent service at lower cost and that neither the long term need for rail transit nor its potential community development benefits were sufficiently clear to justify its expense. UMTA agreed, however, to a grant of $31 million for improvements to Denver's bus system. Further, UMTA agreed to make money available on a loan basis for the advanced acquisition of land so that Denver could keep the optional rail transit open for the future.

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[1] A more extensive discussion of RTD transit activities is contained in Chapter 9.

[2] Voter turnout, however, was less than 20%.

Since UMTA's rejection of the rail transit application, RTD has reduced its staff size by approximately one-third, to a current level of 150 staff members. During this same period RTD has initiated efforts to improve bus service, with concentration in:

- improving the routing, scheduling and fare policy arrangements for existing bus operations and new services (including park-and-ride lots);
- developing a Downtown Transit Mall;
- experimenting with innovative transit concepts, including para-transit services, free fare demonstration projects and joint use of selected community facilities as parking areas.

These efforts are consistent with RTD's perception that they must demonstrate to UMTA an attempt to make maximum use of the existing system. RTD still hopes to obtain UMTA funding for a rail system and is trying to build up ridership in corridors which eventually could have rail lines.

RTD's emphasis on the development of a rail transit proposal has had important consequences for other RTD responsibilities. During rail development efforts, a lower priority by necessity was assigned to certain short range, low capital transportation measures, including TCP measures. However, RTD did implement preferential bus lanes and has assisted both APCD and DRCOG in the implementation of an employer-based ride sharing program. And currently, major emphasis is being given to extensive bus improvements.

The City and County of Denver

The City and County of Denver function as one consolidated jurisdictional unit and have been given home rule authority by the state.[1] The population of Denver was 527,000 in 1975, compared to a metropolitan area total of 1,473,800. Fifty-eight percent of the metropolitan area jobs, however, are within the City.[2]

Although there are several city departments which have input into transportation concerns, the predominant authority is vested in the Department of Public Works, with the Planning Office having a smaller but still important role. Other city departments which have transportation related responsibilities include the Police Department, which enforces traffic laws and is involved in bicycle safety programs; the Zoning Administration, which sets off-street parking requirements; the Department of Parks and Recreation which does the off-street bicycle lane planning, and the Denver Urban Renewal Authority, which operates parking facilities on its cleared land until redevelopment. Figure 2-3, an organization chart of the City

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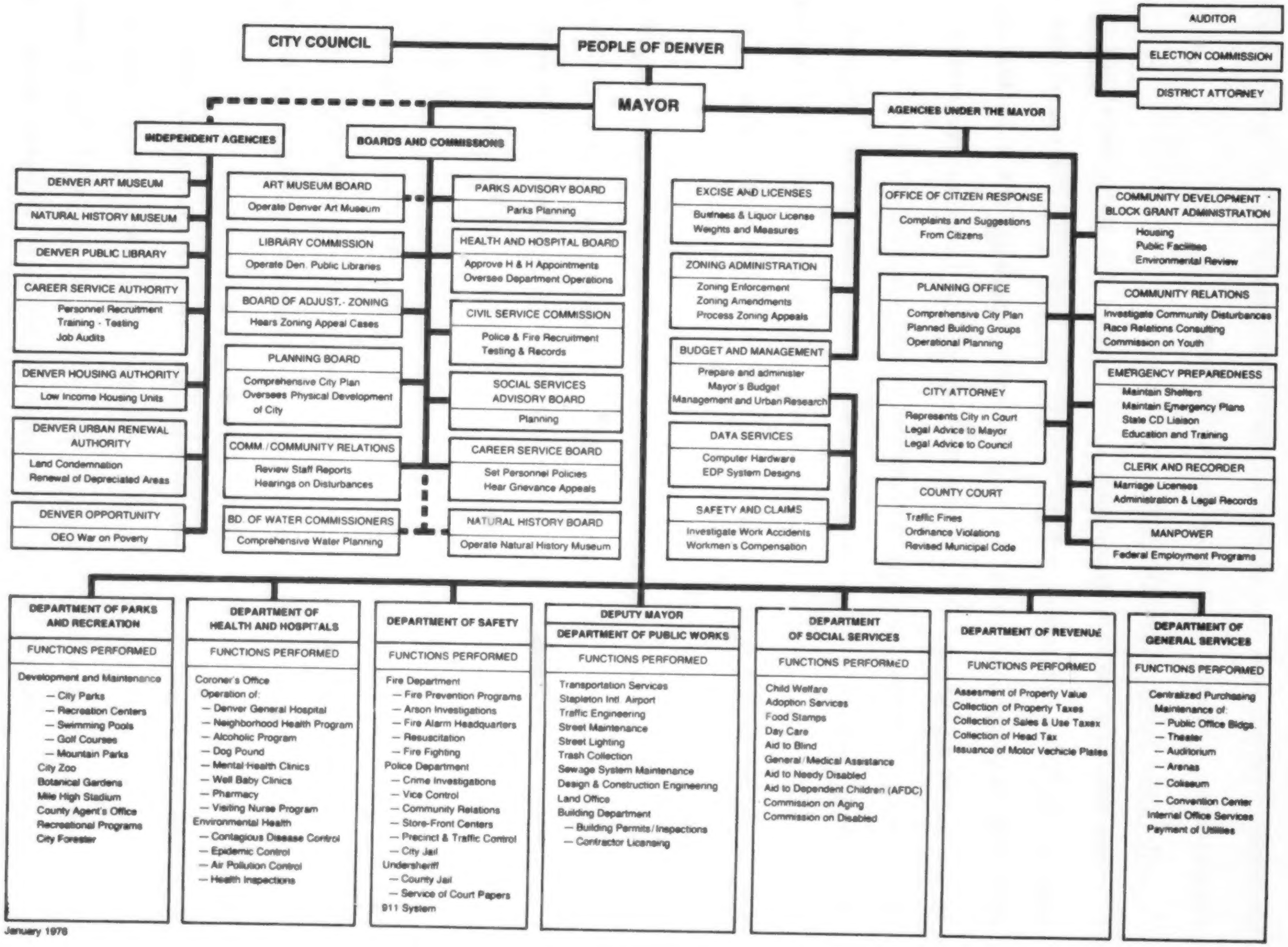
[1] Home rule is the situation in which a state grants a county of municipality limited autonomy to manage their local affairs.

[2] The City and County are referred to as the City throughout the remainder of this section.

FIGURE 2-3
City and County of Denver Government


CITY COUNCIL
PEOPLE OF DENVER
AUDITOR
ELECTION COMMISSION
DISTRICT ATTORNEY
MAYOR
INDEPENDENT AGENCIES
BOARDS AND COMMISSIONS
AGENCIES UNDER THE MAYOR
DENVER ART MUSEUM
NATURAL HISTORY MUSEUM
DENVER PUBLIC LIBRARY
CAREER SERVICE AUTHORITY
Personnel Recruitment
Training - Testing
Job Audits
DENVER HOUSING AUTHORITY
Low Income Housing Units
DENVER URBAN RENEWAL AUTHORITY
Land Condemnation
Renewal of Depreciated Areas
DENVER OPPORTUNITY
OEO War on Poverty
ART MUSEUM BOARD
Operate Denver Art Museum
LIBRARY COMMISSION
Operate Den. Public Libraries
BOARD OF ADJUST. - ZONING
Hears Zoning Appeal Cases
PLANNING BOARD
Comprehensive City Plan
Oversees Physical Development of City
COMM./COMMUNITY RELATIONS
Review Staff Reports
Hearings on Disturbances
BD. OF WATER COMMISSIONERS
Comprehensive Water Planning
PARKS ADVISORY BOARD
Parks Planning
HEALTH AND HOSPITAL BOARD
Approve H & H Appointments
Oversee Department Operations
CIVIL SERVICE COMMISSION
Police & Fire Recruitment
Testing & Records
SOCIAL SERVICES ADVISORY BOARD
Planning
CAREER SERVICE BOARD
Set Personnel Policies
Hear Grievance Appeals
NATURAL HISTORY BOARD
Operate Natural History Museum
EXCISE AND LICENSES
Business & Liquor License
Weights and Measures
ZONING ADMINISTRATION
Zoning Enforcement
Zoning Amendments
Process Zoning Appeals
BUDGET AND MANAGEMENT
Prepare and administer
Mayor's Budget
Management and Urban Research
DATA SERVICES
Computer Hardware
EDP System Designs
SAFETY AND CLAIMS
Investigate Work Accidents
Workmen's Compensation
OFFICE OF CITIZEN RESPONSE
Complaints and Suggestions From Citizens
PLANNING OFFICE
Comprehensive City Plan
Planned Building Groups
Operational Planning
CITY ATTORNEY
Represents City in Court
Legal Advice to Mayor
Legal Advice to Council
COUNTY COURT
Traffic Fines
Ordinance Violations
Revised Municipal Code
COMMUNITY DEVELOPMENT BLOCK GRANT ADMINISTRATION
Housing
Public Facilities
Environmental Review
COMMUNITY RELATIONS
Investigate Community Disturbances
Race Relations Consulting
Commission on Youth
EMERGENCY PREPAREDNESS
Maintain Shelters
Maintain Emergency Plans
State CD Liaison
Education and Training
CLERK AND RECORDER
Marriage Licenses
Administration & Legal Records
MANPOWER
Federal Employment Programs
DEPARTMENT OF PARKS AND RECREATION
FUNCTIONS PERFORMED
Development and Maintenance
— City Parks
— Recreation Centers
— Swimming Pools
— Golf Courses
— Mountain Parks
City Zoo
Botanical Gardens
Mile High Stadium
County Agent's Office
Recreational Programs
City Forester
DEPARTMENT OF HEALTH AND HOSPITALS
FUNCTIONS PERFORMED
Coroner's Office
Operation of:
— Denver General Hospital
— Neighborhood Health Program
— Alcoholic Program
— Dog Pound
— Mental Health Clinics
— Well Baby Clinics
— Pharmacy
— Visiting Nurse Program
Environmental Health
— Contagious Disease Control
— Epidemic Control
— Air Pollution Control
— Health Inspections
DEPARTMENT OF SAFETY
FUNCTIONS PERFORMED
Fire Department
— Fire Prevention Programs
— Arson Investigations
— Fire Alarm Headquarters
— Resuscitation
— Fire Fighting
Police Department
— Crime Investigations
— Vice Control
— Community Relations
— Store-Front Centers
— Precinct & Traffic Control
— City Jail
Undersheriff
— County Jail
— Service of Court Papers
911 System
DEPUTY MAYOR
DEPARTMENT OF PUBLIC WORKS
FUNCTIONS PERFORMED
Transportation Services
Stapleton Intl. Airport
Traffic Engineering
Street Maintenance
Street Lighting
Trash Collection
Sewage System Maintenance
Design & Construction Engineering
Land Office
Building Department
— Building Permits/Inspections
— Contractor Licensing
DEPARTMENT OF SOCIAL SERVICES
FUNCTIONS PERFORMED
Child Welfare
Adoption Services
Food Stamps
Day Care
Aid to Blind
General/Medical Assistance
Aid to Needy Disabled
Aid to Dependent Children (AFDC)
Commission on Aging
Commission on Disabled
DEPARTMENT OF REVENUE
FUNCTIONS PERFORMED
Assesment of Property Value
Collection of Property Taxes
Collection of Sales & Use Taxex
Collection of Head Tax
Issuance of Motor Vechicle Plates
DEPARTMENT OF GENERAL SERVICES
FUNCTIONS PERFORMED
Centralized Purchasing
Maintenance of:
— Public Office Bldgs.
— Theater
— Auditorium
— Arenas
— Coliseum
— Convention Center
Internal Office Services
Payment of Utilities

January 1976

of Denver, illustrates the status and major responsibilities of the various departments, authorities, boards and commissions.

The Department of Public Works

The DPW is a service department, responsible for the general maintenance of the City, including public streets and highways; the operations of Stapleton International Airport; and the enforcement of the building code. It has 1,490 employees. Within the Department are thirteen divisional units, each of which receives a separate budget appropriation. In 1976, DPW's total operating budget was $65,954,000 (5). The Traffic Engineering Division, which has the primary transportation responsibilities within DPW, received $5,198,900 or approximately 8% of DPW's total budget. It has a staff of 369 persons.

The Traffic Engineering Division has long been highly regarded among traffic engineers for its extensive synchronized traffic signal system and its network of one-way streets. The Division's objective in this work, and in most other activities as well, is to improve auto accessibility within the City and to facilitate vehicular traffic flow. The Division has participated in the implementation of Denver's TCP, but has been reluctant to pursue any measure which could be construed as a disincentive to the use of an automobile (e.g., parking management) since this is not perceived to be consistent with City objectives.

DPW is a large and influential agency. In part this stems from the fact that it is an operating agency; but the other factor which increases its influence is the close relationship between the Mayor of Denver and the Manager of DPW, who by law also serves as the City's Deputy Mayor. Additionally, DPW has the authority to act independently on many issues.

For instance, the rates charged at City parking facilities can be changed by the Manager of DPW without input from the City Council. Originally DPW had to obtain City Council approval for their actions, although it did have a 30-day emergency period in which it could act and then obtain City Council approval. However, in 1955, the City Charter was changed by a referendum to make these actions administrative functions to be exercised at the discretion of DPW. Due to a current controversy which is of high visibility within the City, namely the issue of one-way streets, there have been some attempts by opponents of DPW's position to revert this authority back to the City Council. To date they have been unsuccessful.

DPW and most downtown merchants are in favor of the current one-way street patterns because it allows cars to travel into the CBD more quickly. However, many neighborhood associations and environmental groups oppose the one-way street concept because they believe the higher traffic flows and faster moving vehicles cause more noise and accidents in their neighborhoods than would occur with two-way streets. These groups have applied pressure on the City Council to change certain one-way streets back to two-way traffic, but the Council (where 8 of the 11 members voted in favor of this change[1]) has not been able to convince the Mayor (who is backing DPW's position) to change the situation. The City Council acknowledged that if the Mayor refused to go along with the project then they would be unable to implement it, since the Council can appropriate funds for the project but cannot force the Mayor to spend the funds (6). Furthermore, the City

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[1] Voted on December 20, 1976.

Charter gives exclusive power for the operation and control of streets to the Manager of Public Works.

During 1977, twenty state legislators formally requested the Mayor to remove a pair of one-way streets on an experimental basis. As of the time of this writing, no action has been taken by the City on this request.

Planning Office

In contrast to the DPW, the City's Planning Office (DPO) is a much smaller department having less influence over decisions regarding policy and program implementation. They do make recommendations to the City Council and to other departments and, as part of their transportation planning responsibilities, make suggestions to DPW on such matters as parking. However, the final policy decisions reside outside of DPO.

DPO's current annual budget of approximately $1.1 million comes from general City fund appropriations (68%) and grants, and supports a staff of 50. Transportation planning activities receive approximately $204,650 of this budget (19%), of which $50,000 is an UMTA grant for the City's participation in the Unified Work Program (UWP).[1] The 19% includes the portion of DPO's neighborhood, central area and land use planning and statistical analysis which directly contribute to transportation; if these activities are excluded, transportation receives only 11% of the DPO budget. The rest of DPO's budget is for land use and urban design activities not related to transportation.

The Planning Office's transportation budget is only 4% of DPW's Traffic Engineering Division budget. DPO's total budget is less than 2% of the total budget of DPW.

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[1] The UWP is a planning grant administered by DRCOG (as the designated MPO). Local jurisdictions receive a part of these funds to conduct designated planning studies.

While some of the transportation measures on which DPO has worked (e.g., a peripheral parking plan, high occupancy vehicle priority treatment on the East Colfax corridor) are directly related to Denver's air quality transportation control plan, the Planning Office staff associates them more directly with DOT's TSM program. This is in part due to the fact that DPO receives UMTA planning funds to conduct TSM studies.

DPO also is actively involved in RTD's 16th Street bus and retail mall project. Staff members recognize the importance of involving private retailers in the mall planning, and the DPO has estabilshed a close working relationship with Downtown Denver, Inc. (DDI), an influential group of representatives from Denver's large downtown businesses.

Colorado Department of Highways

The Colorado Department of Highways (CDH) was an equal partner with DRCOG and RTD in the JRRP, but has not been an active participant until very recently in the implementation of air quality related transportation measures. Until the appointment in early 1976 of a new executive director, both the headquarters and District 6 (Denver) offices focused on major new construction. During the past two years, CDH has assumed a larger role in air quality and energy conservation programs and has moved in the direction of multi-modal planning and analysis and transportation system management.

Within the headquarters office, air quality analyses have been undertaken to assess the consistency between air quality and transportation programs, a Transportation Plan Restatement process has been initiated, an expanded state bikeway program has been endorsed, and the environmental unit has assumed more general policy analysis and planning responsibilities, reporting directly to the Executive Director. In the development of Colorado's March 1977 State Energy Conservation Plan, it was CDH's Office of Policy Analysis which assumed lead responsibility in developing the plan's transportation component, and CDH funding will be used to help implement the approved transportation energy conservation measures.

These recent initiatives extend, as well, to CDH's District 6 Denver Office. This office has undertaken a series of studies directed toward the implementation of additional preferential treatment facilities for high occupancy vehicles. The district office also will be responsible for CDH's vanpool demonstration program, to be funded with Federal-Aid Highway Urban Systems monies.

Summary of Agency Involvement in TCP Implementation

The preceding discussions have considered the organizational structure and agency characteristics of state, regional, and local agencies having major responsibilities for implementation of the Denver TCP. Table 2-2 summarizes the responsibilities of both of these agencies and of federal and other state agencies potentially involved in the implementation of the six major TCP program measures. The objective is to present an impression of overall agency responsibility, but the descriptions are of necessity generalized representations. For instance, although EPA and DOH (specifically APCC) both have promulgated transportation control regulations, APCC promulgation was made in order to implement the TCP measures promulgated by EPA.[1]

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[1] A more detailed discussion of each agency's involvement in particular TCP measures is contained in Chapters 4-9 of this report.

TABLE 2-2

Summary of Agency Involvement in TCP Measures

TCP Measures / Agencies	Preferential Treatment	Transit Improvements	Parking Management	Employer Based Ride Sharing	Inspection[1] Maintenance	Bicycle Ridership/ Facilities
EPA	Promulgate Fund Monitor Enforce	Promulgate Monitor Enforce	→	→	→	→
FHWA	Fund Review Approve	→	→	Fund Review Approve		Fund Review Approve
UMTA	Fund Review Approve					
State Legislature					Approve Legislate	
Governor					Approve	
CDH	Plan Operate Administer Fund			Plan Operate Administer Fund		Fund Review Approve
DOH (includes APCC and APCD)	Promulgate Monitor	→	→	→	Plan Promulgate Administer Monitor Fund Approve	Promulgate Monitor
County Court	Enforce	Enforce		Enforce		
DRCOG	Plan Review Approve	→	→	Plan Administer Fund Review		Plan Fund Review Approve
RTD	Plan Operate Administer Fund	→				
Denver City (includes all depts. except police)	Plan Administer Maintain Fund Review Approve	Review Approve	Plan Adminis. Fund Review Approve			Plan Fund Maintain Review Approve
Police	Enforce			Enforce	Enforce	→

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[1] Although the Denver TCP also contained the vehicle control measures of retrofitting and high altitude modification, only the Inspection/Maintenance Program is still active (see discussion in Chapter 4).

Table 2-2 also provides an indication of the level of interagency coordination necessary to implement particular TCP measures. It shows that most measures require the participation or involvement of a variety of agencies, and that responsibilities often overlap.

THE ROLE OF PRIVATE INTEREST GROUPS AND PUBLIC ACCEPTABILITY

The influence of private interest groups in the transportation/air quality decision making process cannot be overlooked. Citizen group involvement has increased throughout the nation in recent years and within Denver, in particular, such groups have helped to determine numerous important transportation decisions.

In general, the operating style and orientation of private interest groups differ significantly from that of governmental agencies. Membership in private interest groups is voluntary and most work is non-salaried. The group is usually committed to a particular cause or set of causes which they consider to be in the best interests of the general public. They seek to represent citizens' concerns which, in their opinion, have not traditionally received proper recognitition or consideration. Both their awareness of and willingness to confront particular problems tend to be higher than the average citizen's, although their effectiveness is in part constrained by limited funds, staff and time.

To place the activities of the private interest groups discussed in this section into perspective, two observations are important:

- Private interest groups are advocacy groups and are more willing than public officials to promote measures that are considered to be high risk, high visibility measures.[1]
- Private interest groups place a lower emphasis on the implementation costs of particular measures than do government agencies. Thus, their assessment of the measure's attractiveness and feasibility may often be higher than an agency's assessment for the same measure. Although private interest groups appear to have a good grasp of the deficiencies within the institutional structure, they are less able to identify the problems associated with implementation,in

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[1] Of the six groups discussed in this section, the Auto Club (AAA) represents an exception to this statement. Because of their automobile and service orientation and their larger, more diversified membership, the AAA most frequently does not take a position of leadership in promoting new and innovative measures.

> part because of limited resources and limited familiarity with the agencies' internal organization and procedures.

During the course of this study over 14 environmental and other private interest groups were contacted to determine their perceptions of transportation-related air quality issues, the effectiveness of the decision-making process in addressing these problems, and their group's role and effectiveness in influencing decisions on specific measures of interest. The following discussion focuses on six of these groups:[1]

- League of Women Voters (LWV)
- Sierra Club
- Plan Metro Denver
- Rocky Mountain Center on Environment (ROMCOE)[2]
- Colorado Open Space Council (COSC)[3]
- Rocky Mountain Auto Club (AAA)[4]

Each of these interest groups has been very involved in one or more transportation issues. They have conducted seminars, inviting governmental representatives to attend, have researched issues and written position papers, and have been represented on various citizen committees (e.g., the LWV is represented on the Governor's Ad Hoc Committee on Motor Vehicle Emissions). While not all of the groups have been individually influential, the total effect has been quite noticeable.

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[1] Other private interest groups interviewed (e.g., service industry representatives relative to the I/M program) are considered separately within the TCP program measure chapters as applicable and are identified in Appendix A.

[2] ROMCOE is not an advocacy group; it is a non-profit organization designed to "encourage rational decision making by providing a forum for dialogue between differing points of view." ROMCOE has not been heavily involved in air quality and transportation issues, although they have expressed a desire to get involved. Their main concern has been energy conservation.

[3] COSC is a coalition of approximately 30 environmental groups in Colorado. One of their main emphases has been I/M, and the person interviewed was most knowledgeable on I/M and had little involvement with the other issues.

[4] AAA is a special interest group with a different perspective and mandate than the other private interest groups. The AAA is comprised of paying members who, in turn, receive auto related and other travel services.

The following is a summary of the positions expressed by these groups on particular TCP measures and on related transportation issues.[1] General observations are followed by specific discussion as applicable.

- Preferential Treatment: In general, the preferential treatment concept was favored although the groups had varying opinions on design and operation.

The LWV favors preferential bus lanes although they feel that the program is progressing too slowly. It is their impression that RTD is concerned about the enforcement issue and would therefore like to have as much citizen understanding and approval as possible prior to a large preferential lane effort so that the need for enforcement will be minimized.

The Sierra Club also agrees with the concept but feels that existing rather than newly constructed lanes should be used on the premise that one bus lane is equivalent to three lanes of cars.[2]

Although the AAA similarly agrees with the concept, it is their opinion that the preferential lanes should be reserved for both buses and carpools.

- Transit: Improved transit was advocated by all groups but the nature of their support varied.

The LWV favored RTD's light rail transit application as a way to control urban sprawl. They appear satisfied that even though LRT was not funded, UMTA is making funds available for other transit improvements. The Sierra Club also supported RTD's LRT application but was indifferent about aspects like automation which they thought were not relevant to improved transit. In contrast, the AAA was quite concerned about the proposal and actively opposed it. To demonstrate their opposition, they launched an extensive media campaign against the sales tax levy that RTD sponsored in support of the system.

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[1] Not all of the groups have positions on the same issues, and when a formal position has not been taken, the statements reflect the members' position rather than the group's position. However, in that the representatives interviewed assume lead roles for their group on transit and/or air quality issues, and the number of members on specific subcommittees is small, there is a high probability that the interviewees will be instrumental in shaping the agency's position.

[2] The feasibility of such construction and probability of achieving the necessary charges in modal utilization to justify construction of such facilities are discussed as part of Chapter 6.

Opinions also were expressed on the general transit services provided by RTD. Specifically, the LWV feels that while RTD service into the CBD is fine, neighborhood circulation services should be improved. In their opinion, transit alternatives for shopping and recreational trips must exist before people can even consider not using their automobile. The League feels that it was instrumental in the establishment of RTD.

The Sierra Club representative felt that RTD has been emphasizing suburban commuter trips, citing the establishment of park and ride lots, but that service from within the city to the CBD could be improved. The AAA favors bus mass transit over rail transit since it is both inexpensive and flexible.

Although no group had adopted a formal position on the 16th Street transit mall in the summer of 1977, both the LWV and the Sierra Club indicated informal agreement with the concept. Although AAA also had not adopted a position, many of their actions are closely coordinated with those of Downtown Denver, Inc. who does support the mall.

- Parking Management: Parking management in the CBD has not emerged as a major issue although all groups realized the sensitivity of the situation in relation to downtown business interests. They agreed that any program would have to be worked out with the CBD merchants.

The AAA expressed a concern that a program to limit CBD parking might not achieve the desired effects since people would consequently spend more time riding around trying to locate available spaces and searching for the least expensive parking rates.

- Employer Based Ride Sharing: Employer based ride sharing activities (particularly carpooling) received a mixed reaction ranging from strong support by the AAA to a more sceptical appraisal of the program by the LWV and Sierra Club.

The LWV felt that the carpool program has not been very successful. They suggested that its administration could be improved and noted that employers have not identified carpooling as a high priority. They cited as an example that in one carpooling meeting for employers, the lowest seniority employees were sent as the firm's representatives; the LWV suggested that employers felt that someone had to attend to give the appearance that the firm was meeting their Regulation 9 carpooling obligations. A Sierra Club representative felt that the carpooling program is "almost an absolute flop", expressing the sentiments that buses are more desirable since they provide greater flexibility to people by not requiring fixed time schedules. The AAA, on the other hand, supports the carpooling program, which is consistent with their automobile oriented objectives. They in fact helped start the carpooling program with Downtown Denver, Inc. prior to APCC's Regulation 9 and DRCOG's involvement.

- Inspection/Maintenance: All groups favor I/M, although not all were aware of the legislation's specific points which were the subject of legislative debate at the time of the interviews.

The AAA has been very involved with the legislation since its inception and was generally pleased with the provisions of SB 321. COSC also has promoted the I/M concept and the specific provisions of the SB 321 legislation. COSC has devoted one staff person predominantly to the I/M program. COSC expressed the sentiment that EPA had not been as effective as they had hoped in supporting emission control measures.

- Bicycling: There was general support for bicycling programs, although health and safety issues were of concern.

- One Way Streets: Although the one way street issue in Denver is not a TCP measure, it has recently become a visible economic and environmental issue of the groups contacted.

The one way street concept was opposed by the Sierra Club and Plan Metro Denver on the premise that it expedites auto travel into the CBD and the goal should be to discourage rather than encourage this. Some LWV members also expressed opposition to the one way street concept although no formal position has been adopted.

Observations also were made by the private interest groups on the area's institutional arrangements and on the relative role of incentives and disincentives in accomplishing transportation air quality goals.

- Institutional Arrangements: Institutional arrangements (prior to January 1977) were generally perceived to be inefficient and not conducive to coordinated decision making. There were mixed feelings about the recent willingness of CDH to consider innovative and multimodal measures.

For the past 5-6 years the LWV has been a strong advocate of a state DOT and has been very frustrated that the enabling legislation has not moved forward. They feel that a state DOT is important for coordinating decision making and overcoming the existing institutional fragmentation. Presently the League does not see enough interaction among the separate agencies responsible for air quality and transportation issues.

Regarding MPO designation, the Sierra Club expressed concern that because DRCOG had to be sensitive to the views of its diversified Policy Council, many of its actions would be based on local political considerations. They would have preferred to retain the former triumvirate structure.

- Incentives/Disincentives: It was the general opinion of private interest groups that the public is not ready to accept disincentive measures, especially those that would restrict a citizen's prerogative to drive his automobile. Incentives, however, are viewed as a more desirable and incremental approach. It was felt that the imposition of disincentives may be tolerated during crises when the public is forced to recognize that a problem does indeed exist.

The LWV feels that incentives, particularly financial incentives, are very useful in encouraging shifts in travel behavior, but that people are not ready to penalize themselves for a regional improvement. Although the League feels that a public information program could be useful in generating support for transportation/air quality measures, they are of the opinion that it would have to be a massive and very expensive effort before it would do much good.

The Sierra Club is of the opinion that an in-place alternative must be available before people can be encouraged or required to shift from their automobiles. They also think that it would take an air pollution crisis to alert people to the fact that a problem exists and to make them more accepting of restrictions.

The AAA feels that disincentives are bad and as such would oppose high tolls, license plate schemes to limit CBD parking, etc. They feel that, although the public might be prepared to make limited sacrifices to improve air quality (e.g., vehicle inspection and maintenance), they are not yet ready to limit their driving.

ROMCOE expressed the opinion that the public is not aware of the alternatives for improving air quality and conserving energy. They consider increasing citizen awareness to be a major priority.

SUMMARY OF FINDINGS

1) Prior to the Denver region's current effort on the Transportation Plan Restatement and the State Implementation Plan revision, RTD, DRCOG, CDH, and the state's air quality agency could be characterized by an atmosphere of "cooperative autonomy." The agencies' activities and plans occurred largely independently of each other. While recent changes in Denver's institutional arrangements are intended to improve coordination, it is too early to determine if this objective will be achieved.

2) The activities of Colorado's Air Pollution Control Commission and Air Pollution Control Division have been directed largely towards legislative enactment of a vehicle inspection and maintenance program and improved air quality data and analysis. These activities, combined with APCC's issuance in 1974 of Regulation No. 9 on motor vehicle pollutants, have given APCC and APCD a high level of visibility in Denver's transportation activities. The APCC, and to a lesser degree the APCD, have been strong advocates of measures to reduce motor vehicle emissions. However, internal differences within APCD and more recently between APCC and APCD, have resulted in serious credibility problems for both the Commission and the Division which have hampered their attempts to implement transportation air quality programs.

3) DRCOG, recently designated as Denver's metropolitan planning organization, has been reluctant to become actively involved in either the planning or implementation of air quality measures, in large part because of their controversial nature. Because of its voluntary membership and

lack of independent funding sources, DRCOG must be very sensitive to the views of its diversified member jurisdictions. As a result, DRCOG has difficulty in making policy choices on controversial issues and the policies which it adopts are moderate enough to satisfy a majority of its members.

4) The Regional Transportation District is responsible for the operation and development of Denver's transit system. Since their creation in 1969, they have actively pursued funding for various forms of rail rapid transit while at the same time improving the region's bus system. Since UMTA's rejection in June 1976 of their light rail application, RTD is re-structuring a number of their bus routes and schedules, is developing a downtown bus mall, and has undertaken a number of bus projects located in those areas where they hope eventually to construct rail facilities. RTD feels all of their activities contribute to improved air quality.

5) Several agencies within the City and County of Denver have transportation responsibilities affecting air quality including the Department of Public Works, Planning Office, Police Department, Department of Parks and Recreation and the Denver Urban Renewal Authority. Most influential among these is the Department of Public Works, whose Manager by law also serves as Deputy Mayor of the City. DPW's Traffic Engineering Division, over the years, has implemented numerous projects which improve vehicular flow and provide better access to the central business district. Quite understandably, they have been reluctant to implement measures which would work against these objectives.

6) Until the last year, the Colorado Department of Highways had not

taken an active role in either the planning or implementation of air quality related measures; instead they continued construction-oriented activities. Since 1976, however, CDH has undertaken a series of actions directed toward both energy conservation and improved air quality.

7) Numerous private interest groups in the Denver area have been active in implementing one or more transportation/air quality measures, although air quality is only one of many issues in which these groups are involved. The groups generally believe that the public is not aware of or refuses to recognize the severity of the air quality problem, although many admit that a problem does exist. Further, they believe that the public is not ready to tolerate disincentive measures, especially those that would restrict their freedom to drive, although such measures may be accepted during crises when citizens must confront the problem themselves.

8) Each of Denver's transportation agencies has had its own "agenda" of actions programmed for implementation, some of which are compatible with air quality objectives and others which are not. Local, regional, and state agencies with responsibilities in transportation and air quality have multi-million dollar annual budgets, and implementation of TCP measures is within their financial capabilities; but in most cases it would require both a shift in their priorities and a reallocation of existing staff resources. The agencies frequently have been unwilling to change their priorities to projects which would improve air quality, particularly when such measures are not consistent with agency objectives.

9) Many of the measures contained in Denver's TCP, particularly those perceived as involving auto disincentives, have a low level of public acceptability. Agencies with high visibility and accountability are sceptical about implementing such measures because of the anticipated adverse public reaction. Many transportation measures which intially appear to be implementable in the short range can become long-term efforts when institutional and political factors are taken into account.

10) An extensive set of transportation system management (TSM) activities are presently underway in the Denver region, in large part because of the availability of federal funding. While many of these may contribute to reduced vehicular emissions, air quality generally is not their primary objective.

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(5) City and County of Denver, Department of Public Works, Department of Public Works 1976 Annual Operating Report, February 11, 1977.

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CHAPTER 3

THE AIR QUALITY PROBLEM IN DENVER

OVERVIEW

The Denver Metropolitan area has serious air pollution caused in large part by automobile exhausts. For carbon monoxide and photochemical oxidants, measurements have shown that Denver exceeds the primary national ambient air quality standards on 70-150 days of the year (1). This ranks Denver among the most severely polluted American cities[1] (2). And, because the area is growing rapidly, projections of future pollution levels show that even if auto manufacturers comply fully with the most stringent emission standards called for by the Clean Air Act, Denver is unlikely to attain the ambient standards at any time during this century without additional controls on vehicles.

There is substantial evidence that such a severe and sustained level of pollution has immediate health implications; people with respiratory and cardiac problems run an increased risk of early death, and everyone experiences impaired physical and mental activity during bad episodes.[2] In addition to the health impact, however, Denver's air pollution takes its toll aesthetically, a serious consideration for a city which has prided itself on its pure mountain air and extraordinary views of the Front Range (1, 2).

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[1] In one recent government study (2) of current and projected air quality in major American cities, Denver ranked fourth worst in carbon monoxide and fifth worst in SMOG. Only one other metropolitan area - New York City - ranked so high in more than one pollutant.

[2] A brief description of automotive-related urban air pollution is provided as Appendix H. The discussion includes information on the major pollutants and their health effects, and the difficulties in quantifying benefits from improved air quality.

Although the measurements indicate severe pollution and a brown cloud hangs over the city up to 100 days a year (3), there is no consensus that air pollution is a "problem" for Denver. Instead, there is a clear split of opinion, with many worried advocates of clean-up programs and many others who are convinced that the amounts of air pollution or the implications of the pollution levels have been exaggerated. As in many other areas, the smallness of the air quality data base, the complexity of pollutant formation, the uncertainties in projections of future conditions, and the lack of experience with pollution control measures all have been cited as reasons to go slow in implementing control programs, particularly when those programs place limits on free choice. Denver (and Colorado) has an exceptionally active environmentalist constituency, however, and there are strong state laws and regulations requiring air pollution control, an effective pro-transit lobby, and numerous groups and individuals working hard to promote various control measures.

A more detailed discussion of the air pollution problem in Denver is presented in subsequent sections of this chapter, but, before delving into the essentially technical issues of defining the scope and severity of the problem, it is important to establish an understanding of the general context of urban air pollution control. This is done in the following section.

DENVER'S AIR QUALITY

Physical Factors

Denver's air quality problem is attributable to a number of social, topographical, and meteorological factors which together are unique among large American cities. Altitude is perhaps the first one which comes to mind. The "mile-high" city has "thin" air which decreases the efficiency of combustion in automobile engines and increases the rate of emissions. According to EPA, auto emissions are significantly worse at high altitudes, particularly for carbon monoxide.

The topography of Denver does not trap the pollution as effectively as in Los Angeles or San Francisco, but physical characteristics nevertheless are important in the genesis of severe photochemical smog. Metropolitan Denver lies within the South Platte River drainage basin. The river flows from southwest to northeast (Figure 3-1) through the center of Denver, with land elevation generally decreasing toward the northeast. The mountains rise about 3,000 feet above the city in the west and 1,000 - 2,000 feet in the southwest. This pattern results in diurnal upslope-downslope (or "drainage") winds, and frequent "eddies" where the winds interact with mountain ridges and canyons. Typical wind patterns are shown in Figures 3-2 and 3-3. At times, these winds may help to disperse the pollution cloud by moving it to rural areas northeast of Denver, but often they deposit dense concentrations in dead areas and up against the mountains.

The mountains also permit frequent inversions to develop. A shift in wind from the north to the west causes a cool polar air mass at the surface to be overlain by a warmer westerly flow from across the mountains.

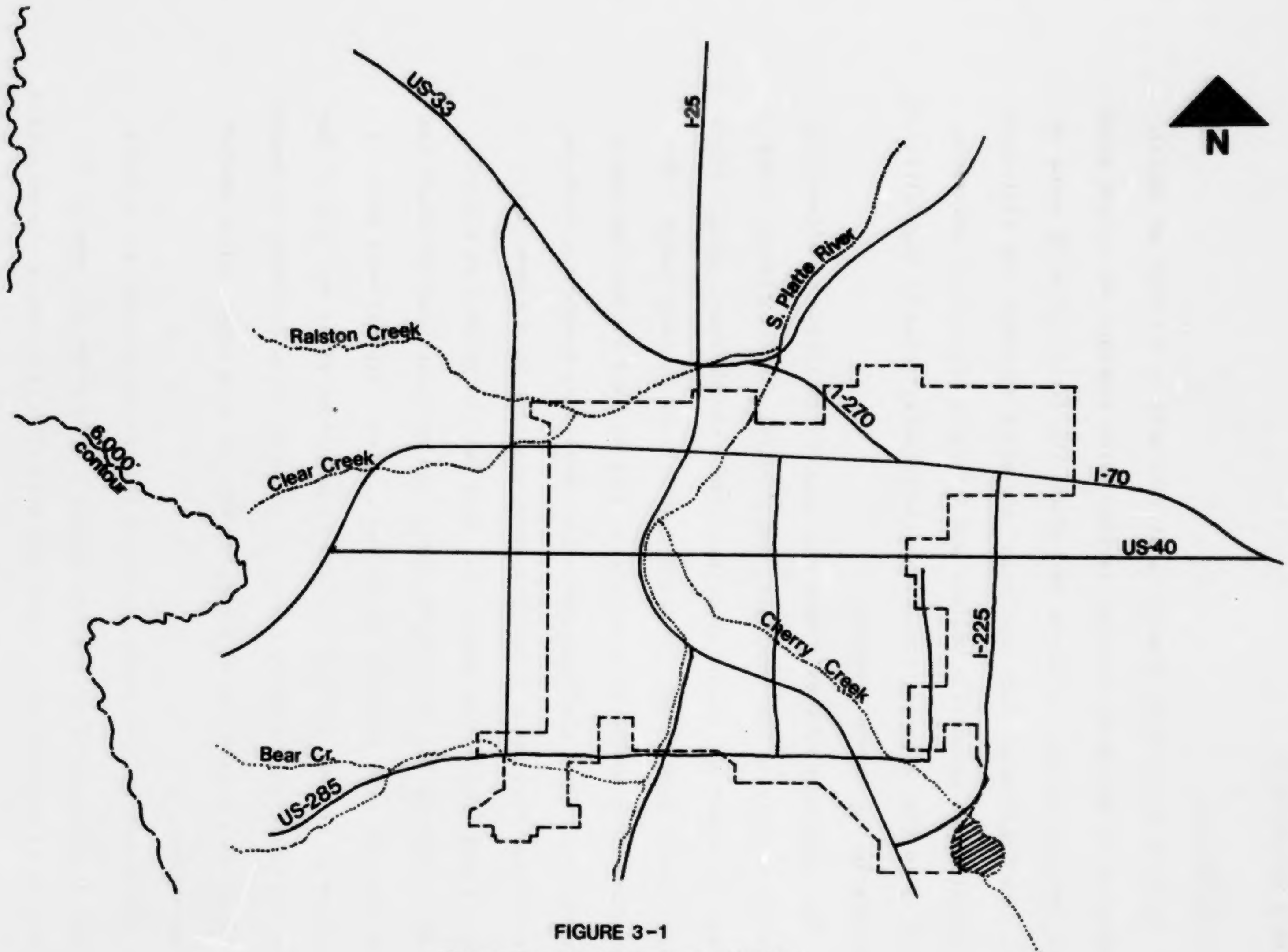
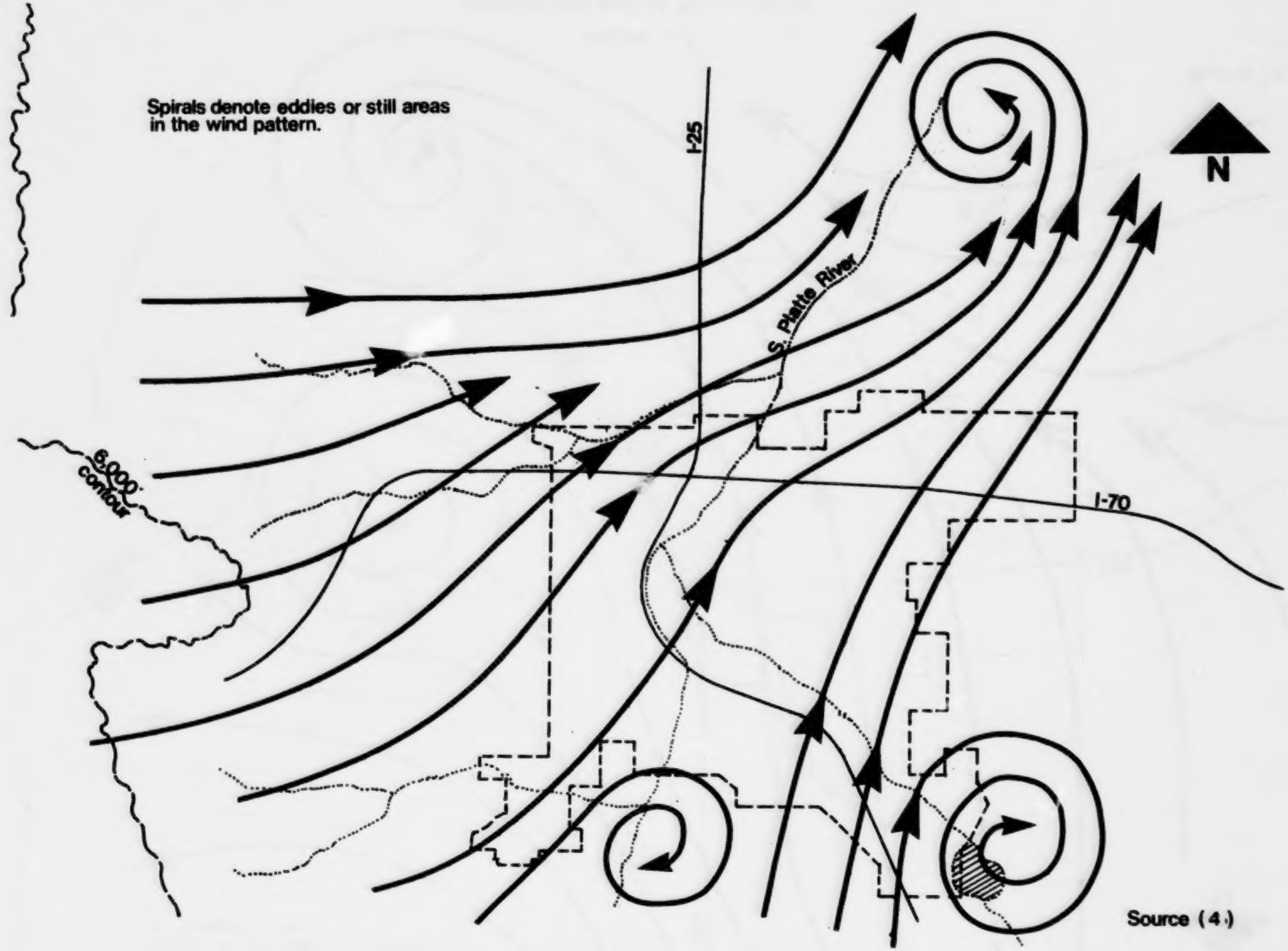

N
US-33
I-25
S. Platte River
Ralston Creek
I-270
6,000' contour
Clear Creek
I-70
US-40
Cherry Creek
I-225
Bear Cr.
US-285

FIGURE 3-1

Primary Topographic Features Affecting Air Quality in Metropolitan Denver


I-25
I-70
S. Platte River
6,000' contour
N

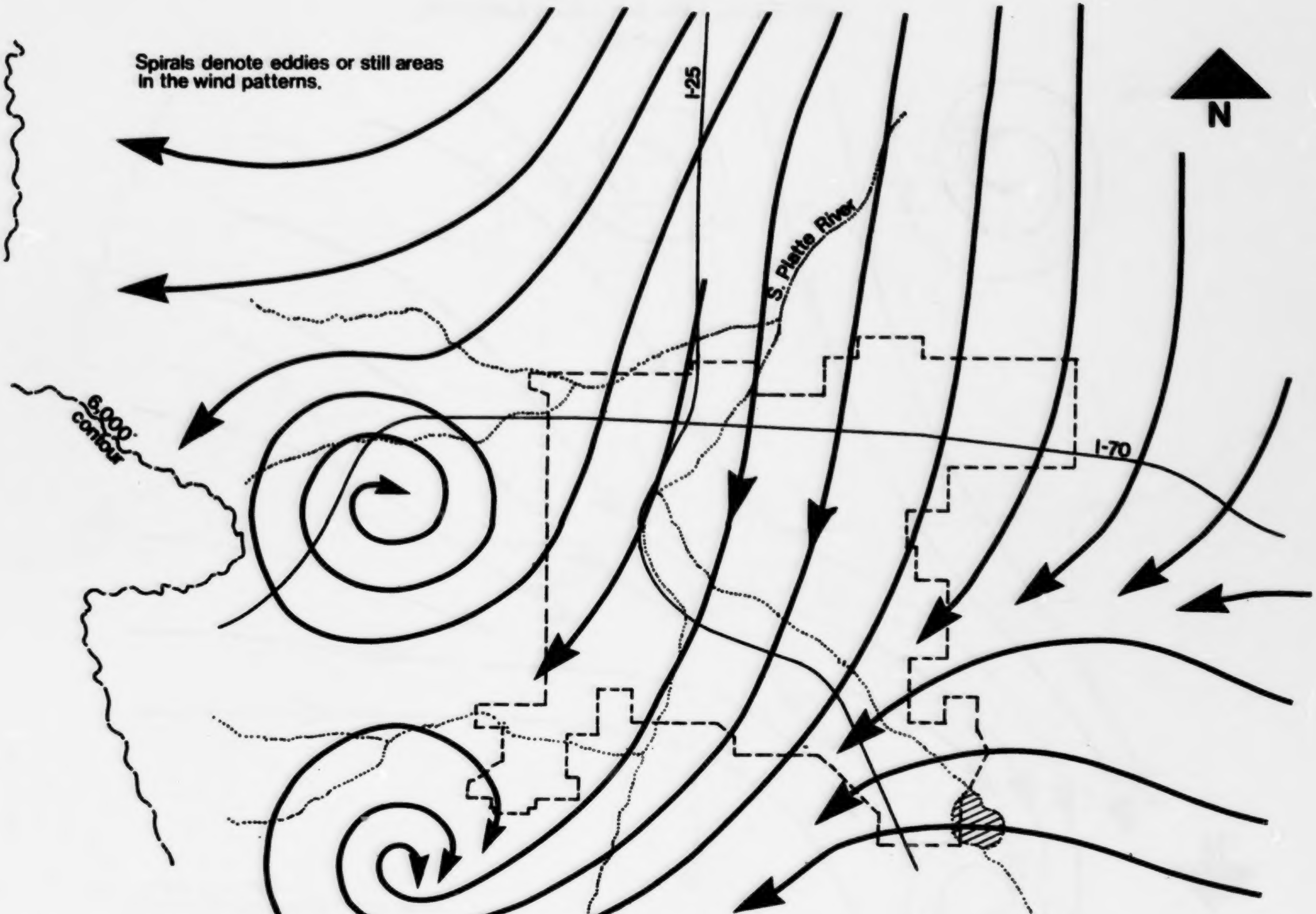
Spirals denote eddies or still areas in the wind pattern.

Source (4)

FIGURE 3-2

Typical Early Morning Downslope Wind in Denver

Spirals denote eddies or still areas in the wind patterns.


N
I-25
I-70
S. Platte River
6,000' contour

Source (4)

FIGURE 3-3

Typical Midday Upslope Wind in Denver

These inversions are strongest and most persistent in winter, especially with snow cover. Partly as a result of the inversions, Denver has an average morning mixing layer which is the thinnest of any major city in the country. By contrast, the afternoon mixing layer tends to be extremely thick, so Denver's morning pollutant cloud may be diluted considerably by the afternoon.

Denver's development patterns and its automobile tradition also contribute to very high per-capita daily emissions. Residential patterns are predominantly low-density and suburban-oriented, and activity centers are dispersed, a combination which is thought to promote longer trips and to discourage transit use.

Some of the most severely polluted towns in metropolitan Denver have shown the greatest growth in recent years. A "carrying-capacity" based land use plan for Denver in the early 1970's called for minimal future growth of towns to the west and southwest of the city in large part because of the buildup of pollutants by diurnal winds. Yet these towns contain some of the most attractive residential sites available in the entire metropolitan area, and it has been impossible under existing law to prevent such growth (especially without the cooperation of the towns). Consequently, the number of people exposed to dangerous pollution concentrations has risen dramatically.

This unique combination of development patterns, travel behavior, and physical attributes is the fundamental cause of Denver's auto-related air pollution problem. Denver is fortunate in not having stationary source pollution to match. Facilities which produce large amounts of nitrogen and sulfur oxides are less common that in other cities of similar size. Table 3-1 shows the relative contribution of automobiles in comparison with other emission sources for the most important pollutants in the Denver area. For comparison, the same data for Baltimore, Maryland, a metropolitan area of similar size, also are shown.

Air Quality Monitoring and Analysis

In the past seven years, air pollution has become an important focus of government action in Denver. For several years the Colorado Department of Health has operated monitoring stations in metropolitan Denver to record pollution levels in a number of different areas (Figure 3-4). At the same time, the Colorado Department of Highways, the Department of Health, and DRCOG have developed increasingly sophisticated regional air quality models for use in projecting data from the individual monitoring stations over the entire region. For CO and photochemical oxidants, a computer model developed by Systems Application, Inc. (SAI) is used for simulating pollutant concentrations over time and space as a function of atmospheric transport and chemical reaction.[1] Input to this model consists of meteorological data and emission totals for autos, trucks, aircraft, and stationary sources in each cell of a 30 x 30 grid covering the Denver metropolitan area (each cell is one mile on a side). Outputs are the anticipated pollutant concentrations in each cell over time. The model is calibrated by adjusting the parameters until projections for the cells in which monitoring stations are located agree with actual measurements.

---

[1] Appendix G contains a summary description of this model and a discussion of the underlying assumptions.

TABLE 3-1

Percent of Total Areawide Emissions Contributed By Each Major Source Category

Denver

	Autos	Other Vehicles	Stationary Sources
CO	73	26	1
HC	55	26	19
NO_x	32	15	53

Baltimore

	Autos	Other Vehicles	Stationary Sources
CO	72	26	2
HC	25	13	62
NO_x	20	11	69

Source: (5), pp. 56 and 102.

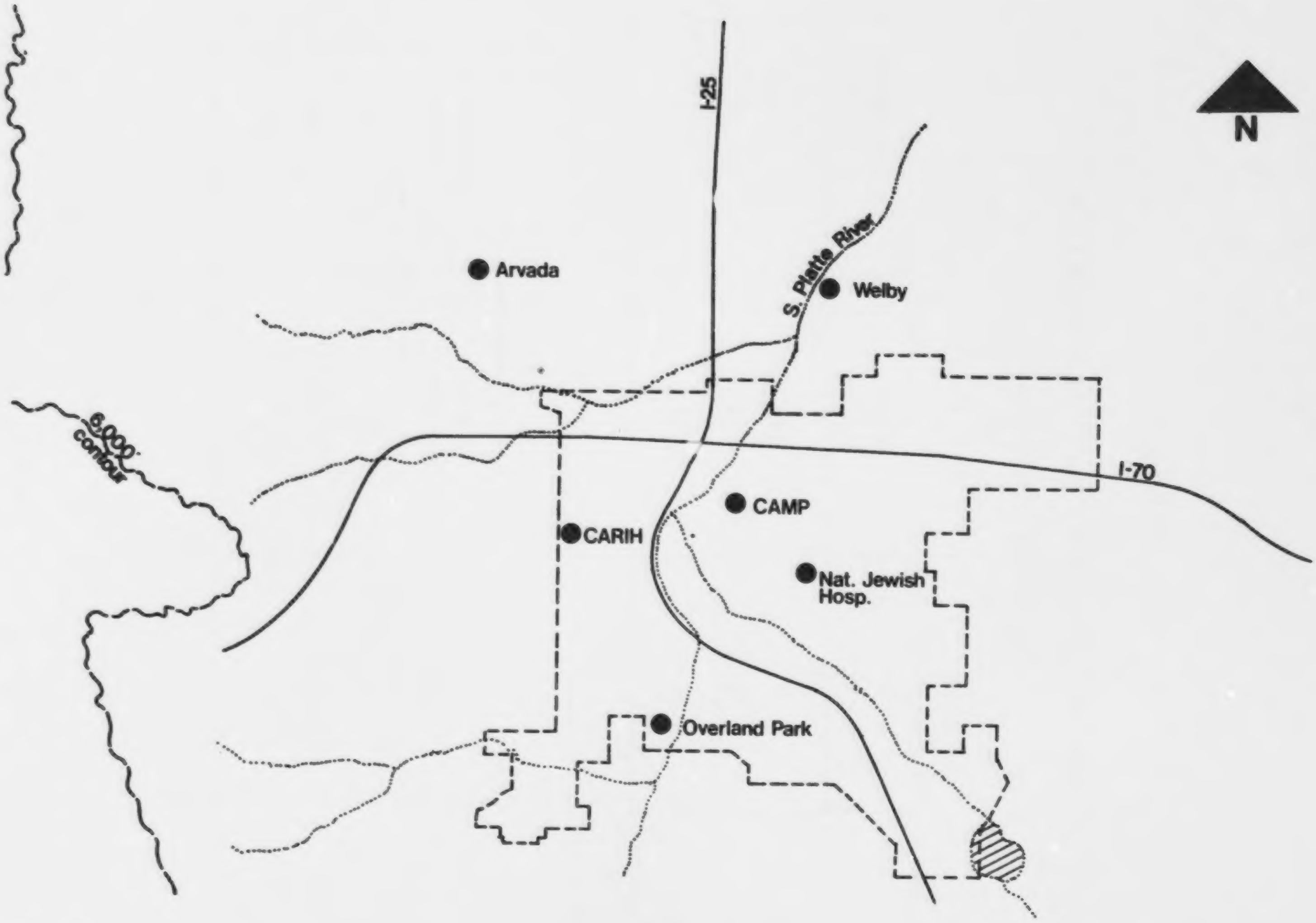

N
I-25
I-70
S. Platte River
Arvada
Welby
CAMP
CARIH
Nat. Jewish Hosp.
Overland Park
6,000' contour

FIGURE 3-4

Location of Air Quality Monitoring Stations

For NO_2 and particulates, the Climate Dispersion Model (CDM) is used, because it produces the desired yearly averages rather than hourly or daily concentrations. In addition to projecting current monitoring data over the region, both models are used to predict pollutant concentrations in future years. The results of these monitoring and modelling activities are summarized in the following sections.

Carbon Monoxide[1]

CO has a double peaked diurnal pattern reflecting the periods of rush hour traffic. The highest level of CO occurs in the winter months and indicates a strong relationship between the inversion height and CO concentrations. High CO levels are a problem throughout the region, both in major suburban activity centers and in the CBD.

Table 3-2 summarizes the number of days the one-hour CO standard was exceeded in 1975 at the six permanent monitoring stations. Since the standard can be exceeded once each year, the second highest maximum value indicates the amount of violation. The number of days with violations indicates the severity of the problem. Two of the monitoring stations recorded violations of the one-hour CO standard in 1975. These stations are more exposed to heavy traffic than are others.

Table 3-3 illustrates the days of violation of the one-hour CO standard as measured at the CAMP station. The number of violation days is small, with most occurring in November, December, and January. No annual trends are apparent in these results.

---

[1] This and the following two sections draw heavily upon model results presented in Reference (4). The contribution of the authors of that report is gratefully acknowledged.

TABLE 3-2

Violations of One-Hour Carbon Monoxide Standards

Station	No. of Days Standard was Exceeded	No. of Days Monitored	2nd Max. Value (PPM)	Max. Value (PPM)
CAMP	7	347	46.1	47.2
Natl. Jewish	5	267	43.1	51.4
Arvada	0	345	23.5	26.9
CARIH	0	333	27.3	27.9
Overland	0	313	22.5	28.8
Welby	0	340	27.5	30.8

Standard = 35 ppm

Source: (4)

Table 3-4 shows the number of days in 1975 that the eight hour CO standard was exceeded at the six permanent monitoring stations. Violations of the eight-hour CO standard are more frequent; all the stations have a number of days when at least one violation of the eight-hour CO standard occurred. Second highest eight-hour CO values range from 33 percent to 157 percent over the standards. Since the eight-hour CO standard is violated more frequently and severely than the one-hour CO, the eight-hour values should be used to determine the amount of CO emission reduction necessary for the Denver region.

Table 3-5 illustrates the monthly violation days of the eight-hour CO standard as measured at the CAMP station. A decrease in the average monthly violations has occurred since 1971.

TABLE 3-3

CAMP Station 1-Hour Violation Days

Carbon Monoxide

	1975	1974	1973	1972	1971	1970	1969	1968
January	0	2	2	3	3	1	1	1
February	1	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	**	0	0	0	0	0	0
August	0	**	0	0	**	0	0	0
September	0	**	0	0	**	0	0	0
October	0	0	**	0	0	0	1	0
November	2	3	3	0	2	1	4	2
December	4	4	3	0	7	5	5	3
Total	7	9	8	3	12	7	11	6
Max*	47	40	57	43	59	59	55	--
2nd Max*	46	61	46	41	51	56	44	--

*Units in ppm.
**Data unavailable due to instrument malfunction.
Standard = 35 ppm.

TABLE 3-4

Violations of Eight-Hour Carbon Monoxide Standards

Station	No. of Days Standard was Exceeded	No. of Days Monitored	2nd Max. Value (PPM)	Max. Value (PPM)
CAMP	72	347	22.3	22.6
Natl. Jewish	50	267	23.1	24.0
Arvada	12	345	14.0	16.0
CARIH	26	333	21.9	23.3
Overland	5	313	12.0	15.0
Welby	12	340	16.6	19.0

Standard = 9 ppm

Source: (4)

TABLE 3-5

CAMP Station 8-Hour Violation Days

Carbon Monoxide

	1975	1974	1973	1972	1971	1970	1969	1968
January	12	21	20	19	22	22	13	14
February	9	9	11	18	18	9	6	7
March	4	7	9	6	13	3	6	4
April	3	4	0	6	9	3	3	4
May	0	0	1	5	6	3	3	2
June	0	1	0	10	3	3	3	3
July	0	**	4	11	1	5	2	1
August	0	**	1	11	**	14	4	1
September	0	**	8	15	**	10	15	7
October	9	6	**	16	19	20	20	13
November	14	12	17	18	25	21	21	13
December	21	13	15	19	25	26	24	14
Total	72	73	86	154	141	139	120	83
Max*	22.6	30.3	37.0	28.9	33.2	32.3	24.4	--
2nd Max*	22.3	28.9	29.4	28.7	29.7	27.9	24.1	--

*Units in ppm.
**Data unavailable due to instrument malfunction.
Standard = 9 ppm

Source: (4)

SAI model output for CO concentrations under winter conditions indicates that approximately 30 square miles are in violation of the one-hour standard (Figure 3-5). This continues through 1980, with the maximum background concentrations occurring in the center of the region. By 1985 only a few violations occur; all violations are eliminated by 1990. This trend reflects the federal emissions controls required for automobiles as of 1976.

A better indication of CO exposure levels is provided by Figure 3-6. Numerous "hot spots", located near major roadway intersections or activity centers, are seen to persist through the year 2000, but, in general, the area of heavy CO concentration shrinks until 1990, then remains constant.

The eight-hour CO standard would be exceeded by up to 300 percent in approximately 219 square miles under present day winter conditions (Figure 3-7). With the traffic volume increase and the minimal vehicle emission reductions expected by 1980, the exceedance area would increase to 256 square miles. A significant reduction in vehicle emissions of CO by 1985 results in a 96 percent decrease in the area exceeding the eight-hour standard to about 61 square miles, but spot violations within that area still are 200 percent above standards. The area in violation is expected to shrink to 17 square miles by 1990 and to 16 square miles by the year 2000.

The eight-hour CO standard is violated to a much greater extent in Denver than is the one-hour standard. Figure 3-7 indicates that the highest eight-hour CO values are observed in the central city, with additional hot spots at major intersections throughout the metro area. High concentrations are virtually the same in 1975 and 1980. In 1985, concentrations are reduced to the point where only the core area exceeds the standards. In 1990 and the year 2000, the maximum levels are near 9 ppm, and it is not clear that there will be violations.

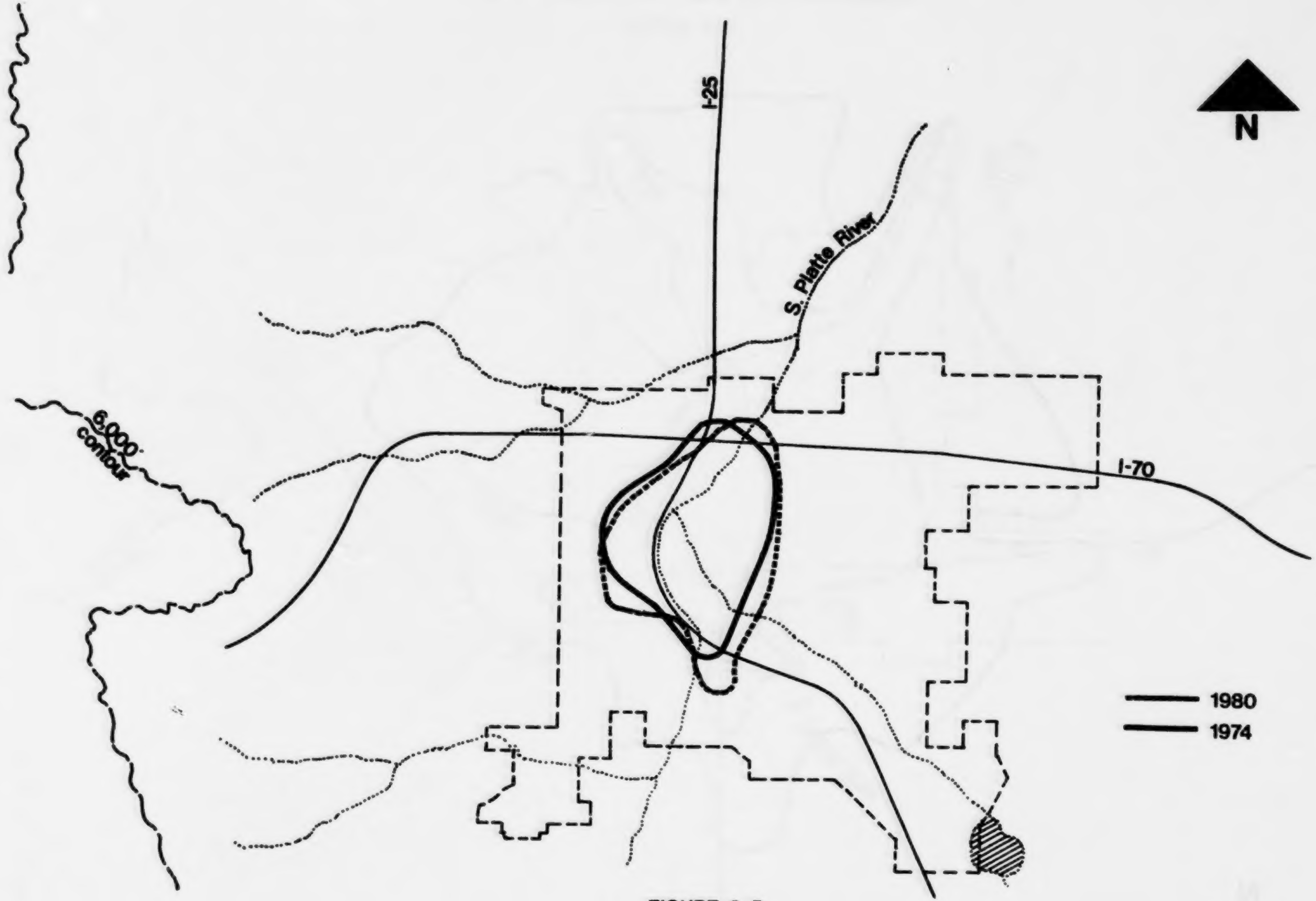

N
I-25
S. Platte River
I-70
6,000' contour
1980
1974

FIGURE 3-5

Perimeter of the Violation Area for the 1 Hour CO Standard

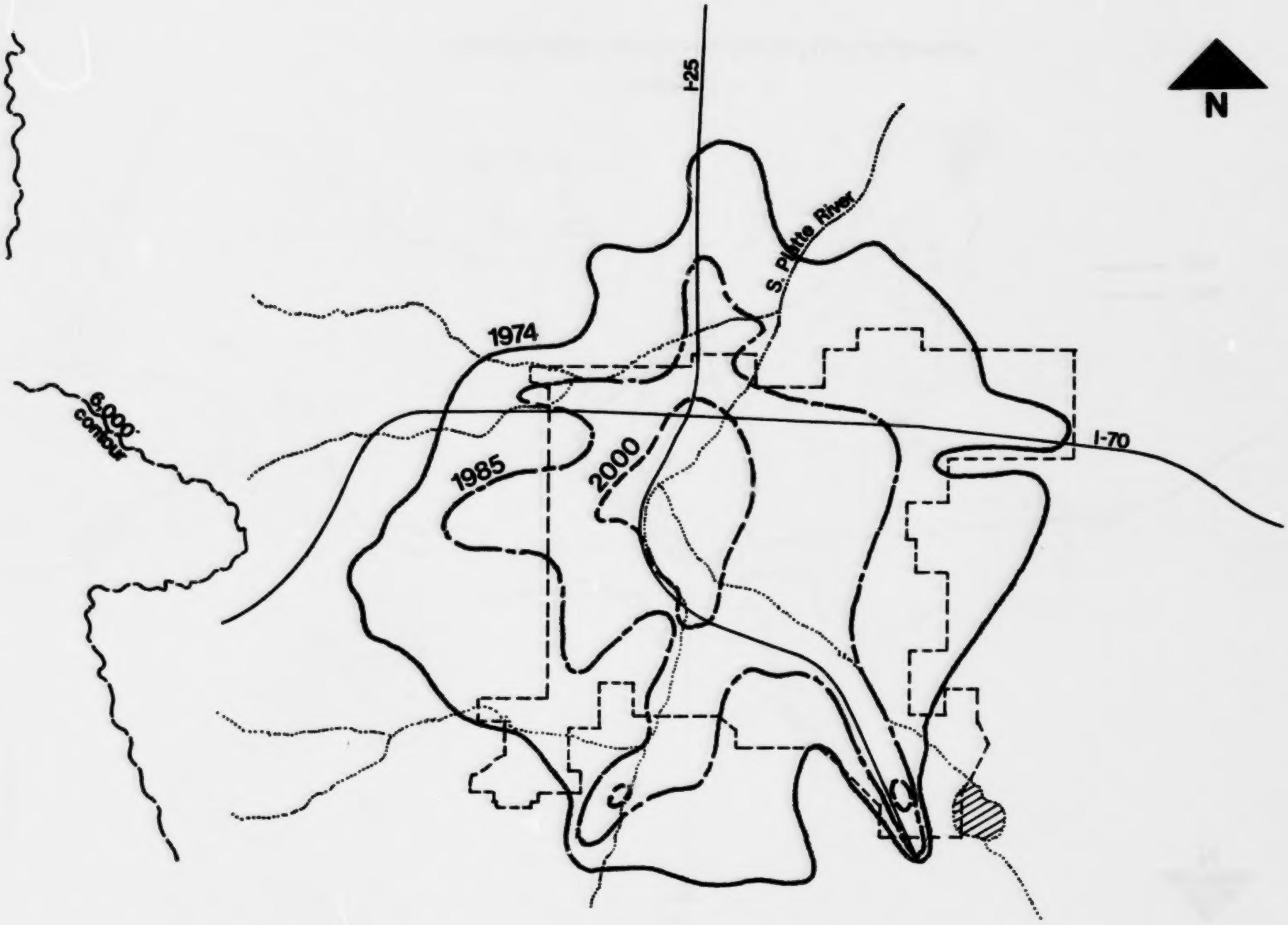

N
I-25
I-70
S. Platte River
1974
1985
2000
6,000' contour

FIGURE 3-6

Second Highest One-Hour CO Concentration:
Perimeter of Area Having 12 ppm or Greater

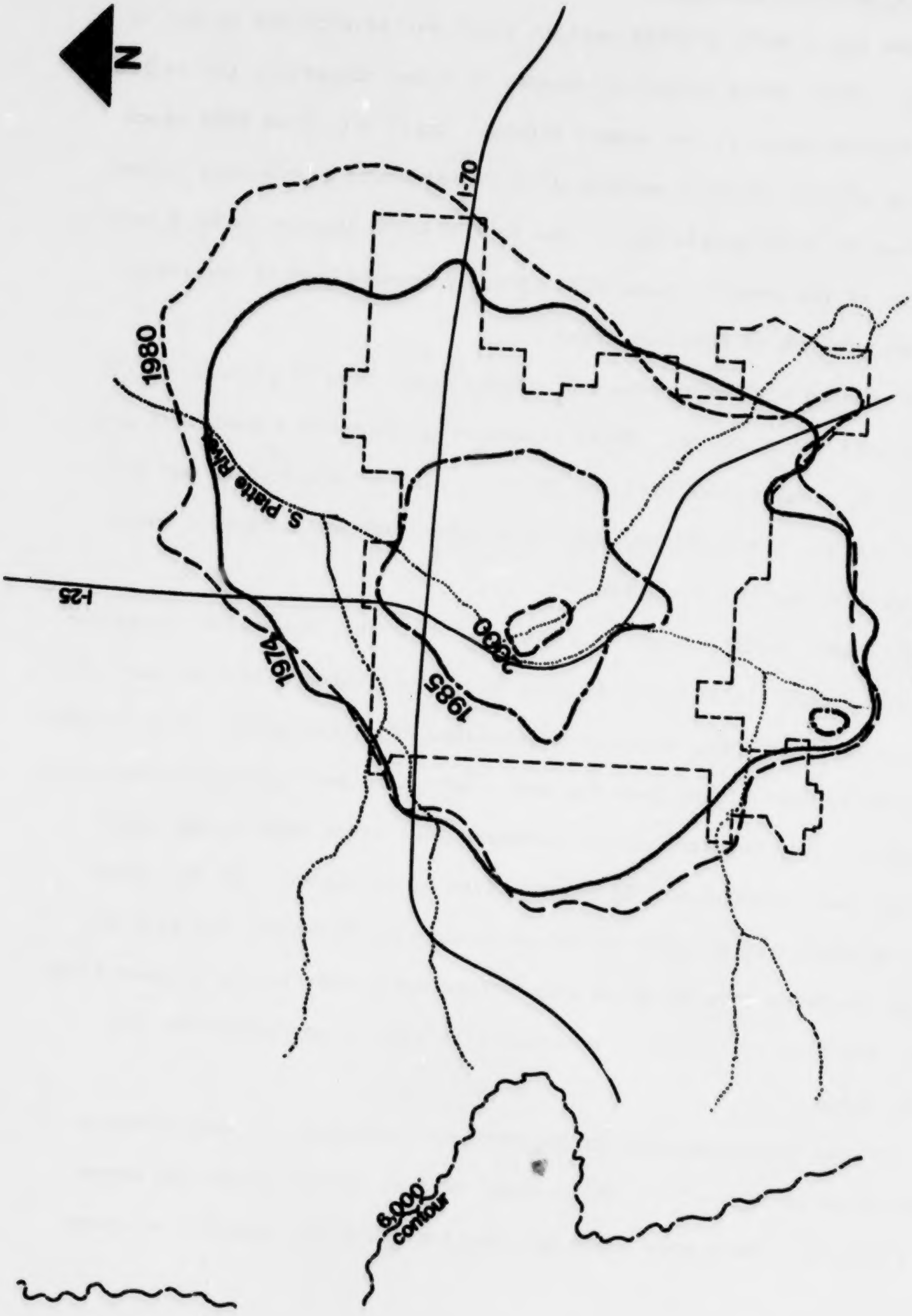

N
I-70
1980
S. Platte River
I-25
1974
1985
2000
8,000 contour

FIGURE 3-7

Violation of the CO 8-Hour Standard: Perimeter of the Violation Area

Ozone (Photochemical Oxidant)

Ozone has a daily peaking pattern which varies with the amount of sunshine. Since ozone formation depends on solar intensity, the highest concentrations occur in the summer months. Table 3-6 shows that ozone primarily affects areas in metropolitan Denver where people live rather than areas in which people work. The CAMP Station appears to be a poor indicator of the overall ozone situation; it unquestionably underestimates the problem in suburban areas.

The second highest one-hour O_3 values range from 35 percent to 132 percent over the standard. Every permanent station had a number of days when the O_3 standard was violated in 1975. The Arvada Station had the highest number of violations, while the urban CAMP and National Jewish Hospital Stations had the lowest.

SAI model results shown in Figure 3-8 indicate that ozone concentrations may exceed the standard by over 50 percent through 1980 in about 500 square miles. In 1986, automotive emissions of nitric oxides (NO) are projected to be much higher than for any other year, and hydrocarbon emissions are lower. This combined effect produces less ozone than in any other previous year, with about 384 square miles of violation. By the years 1990 and 2000, nitric oxide emissions again will decrease, and with NO_2 and hydrocarbons once again in proportions more conducive to oxidant formation, the area in violation actually will rise to approximately 440 square miles.

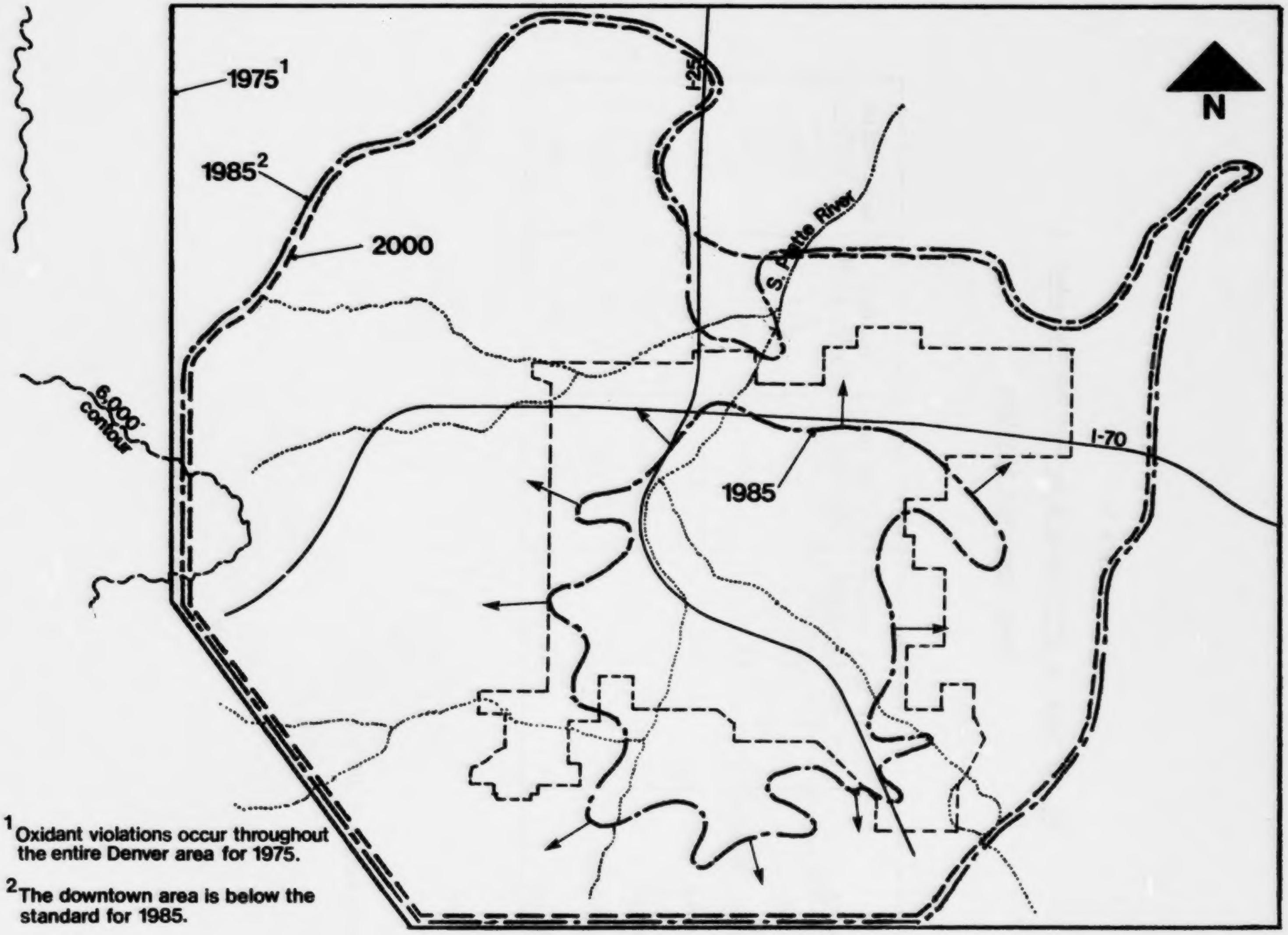
Oxidant concentrations in the west and southwest are more clearly illustrated in Figure 3-9, which shows oxidant levels at .01 ppm above the standard. These maps leave no question about the severity or extent

TABLE 3-6

No. of Days in 1975 Ozone Standard Was Exceeded at State Operated Stations

Station	No. of Days Standard was Exceeded	No. of Days Monitored	2nd Max. Value (PPM)	Max. Value (PPM)
CAMP	17	325	.115	.132
Natl. Jewish	12	266	.108	.110
Arvada	71	315	.178	.197
CARIH	57	341	.135	.140
Overland	43	338	.135	.139
Welby	62	346	.177	.182

Standard = 0.08 ppm


N
1975[1]
1985[2]
2000
1985
I-25
I-70
S. Platte River
6,000' contour

[1] Oxidant violations occur throughout the entire Denver area for 1975.

[2] The downtown area is below the standard for 1985.

FIGURE 3-8

Perimeter of the Violation Area for the One-Hour Oxidant Standard

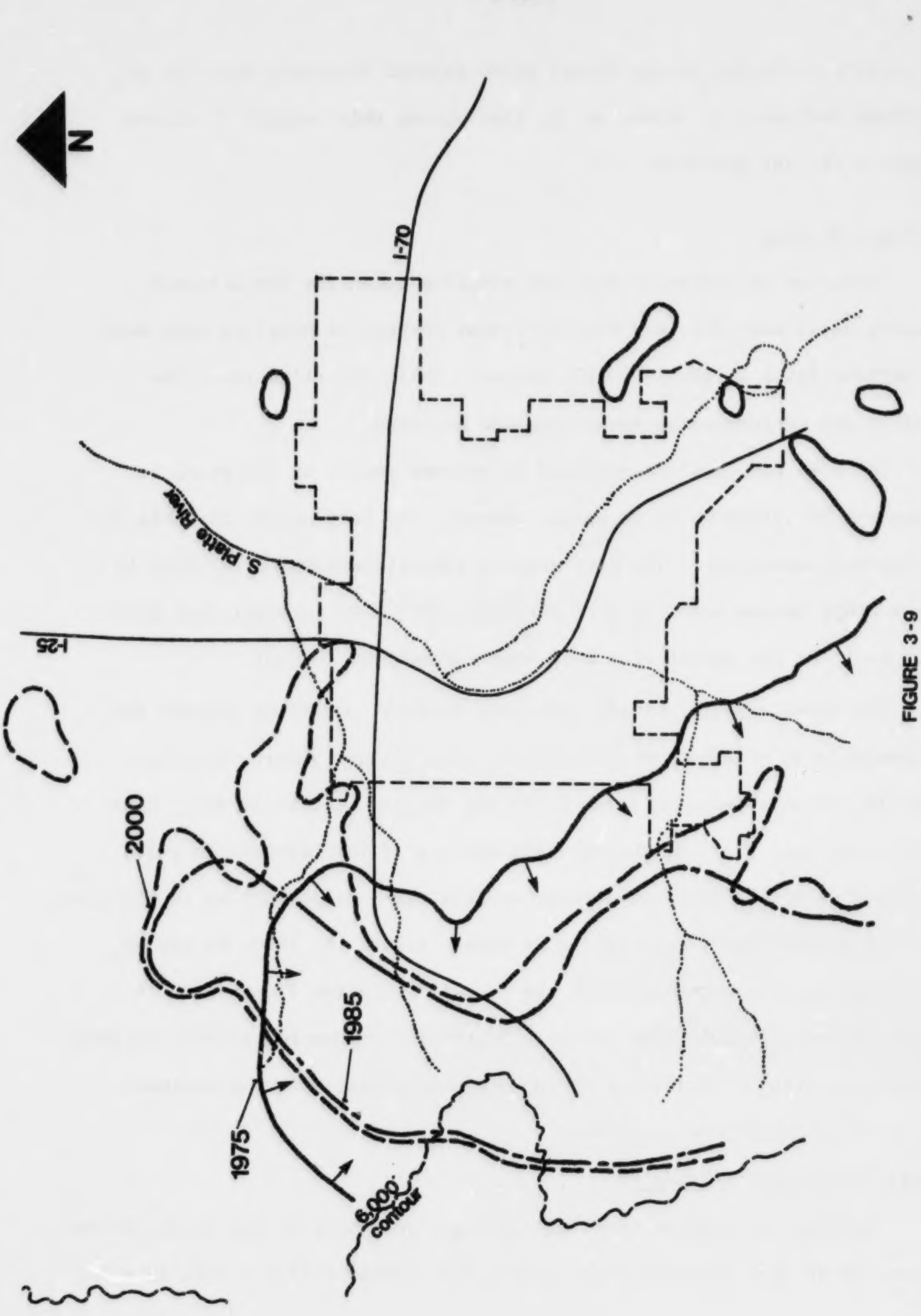

N
I-70
I-25
S. Platte River
2000
1985
1975
6,000 contour

FIGURE 3-9

One-Hour Oxidant Concentration:
Perimeter of the Area Exceeding .09 ppm

of oxidant pollution in the Denver area--federal standards will not be attained over most of Denver at any time during this century if present policies are not modified.

Nitrogen Dioxide

There was no federally approved sampling technique for nitrogen dioxide until mid-1976, and four different methods of sampling were used at various times in the 1965-1976 period. Table 3-7 illustrates the monthly and corresponding annual average NO_2 data.

The 0.05 ppm level is exceeded in various months of the year, but since the NO_2 standard is an annual average, the last column in Table 3-7 is the most important. The data seem to indicate a significant jump in the monthly values starting with November, 1973 (~40 percent), but this also could be the result of a more accurate sampling method.

SAI model results for NO_2 show that present conditions violate the standards by up to 12 percent in two square miles (Figure 3-10). At present, however, vehicle emission rates of NO and NO_2 are relatively low. Emission rates will increase through 1985 because of the increase in autos equipped with catalytic converters; at that time, violations up to 30 percent above standards are predicted for 19 square miles. By 1990, NO and NO_2 emissions decline somewhat, with the area in violation dropping to 14 square miles. By 2000, the increase in traffic volume and airport activity pushes the area of violations up to 23 square miles, with the maximum being 40 percent above standards.

Total Suspended Particulates

Eighteen particulate sampling sites are currently in use in the Denver metropolitan area (Figure 3-11). Table 3-8 contains 1970 - 1975 data for

TABLE 3-7

CAMP Station, Monthly Mean NO_2 Concentrations (ppm)

	J	F	M	A	M	J	Jl	Au	S	O	N	D	Annual Average
1965	-	.05	.04	.03	.03	.03	.03	.04	.03	.04	.04	.04	.036
1966	.04	.04	.03	.03	.03	.03	.02	.03	.03	.04	.04	.04	.033
1967	.04	.03	.04	.02	.02	.02	.04	.04	.04	.04	.05	.05	.036
1968	.05	.04	.03	.03	.03	.03	.03	.03	.03	.04	.04	.04	.035
1969	.04	.04	.03	.02	.03	.03	.03	.02	.03	.04	.04	.04	.033
1970	.04	.03	.03	.03	.03	.03	.05	.05	.05	.04	.04	.04	.038
1971	.03	.03	.03	.03	.03	-	-	-	-	.04	.04	.04	.034
1972	.03	.04	.04	.02	.03	.03	.03	.03	.03	.04	.06	.08	.038
1973	.08	.06	.06	.04	.04	.04	.06	.04	.04	-	.05	.07	.053
1974	.08	.06	.04	.05	.03	.04	.04	.04	.04	.05	.04	.05	.050
1975	.05	.06	.05	.06	.04	.04	.05	.05	.05	.05	.05	.05	.050

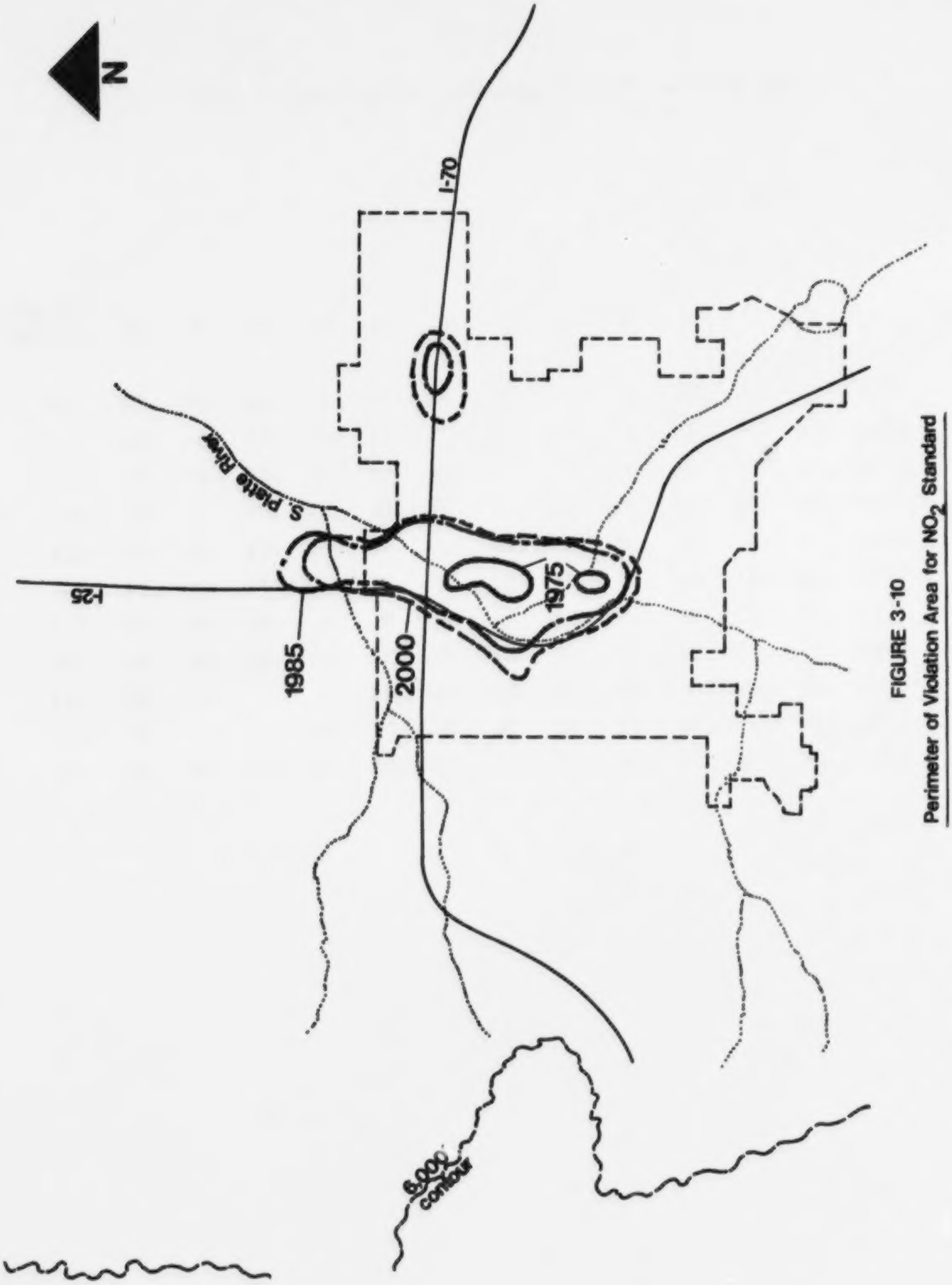

N
I-70
I-25
S. Platte River
1975
1985
2000
6,000' contour

FIGURE 3-10

Perimeter of Violation Area for NO_2 Standard

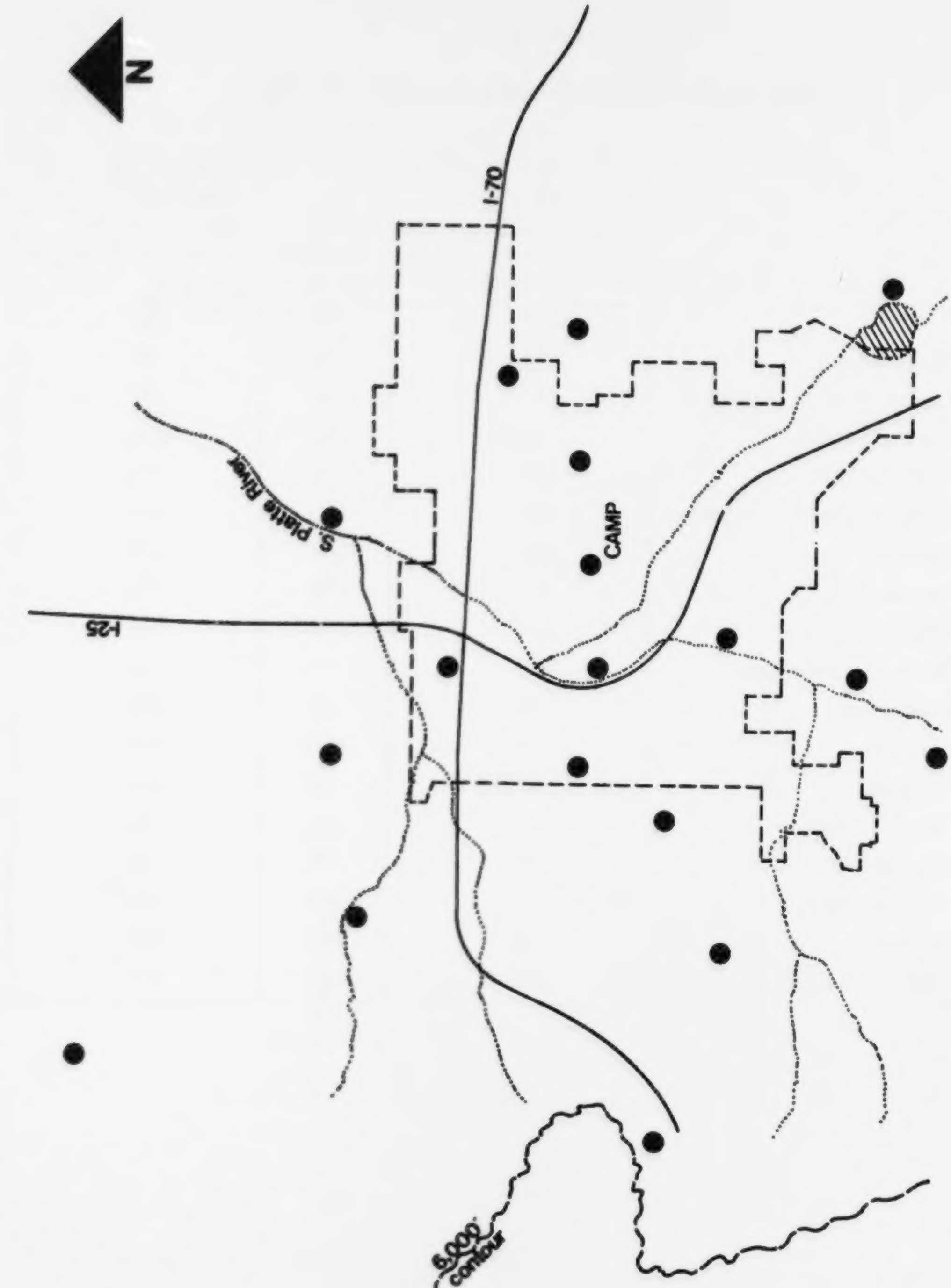

N
I-70
I-25
S. Platte River
CAMP
6,000' contour

FIGURE 3-11
Particulate Monitoring Sites

TABLE 3-8

Summary of Historical Particulate Sampling Data

	1970-75 Maximum Value of Running Annual Mean ug/m^3	1975 Maximum Value	Percent of Time in Violation of State Standard During 1970-75*
CAMP	205	180	100
Hull Photo	NA	NA	NA
State Health Building	85	80	100
Gates Rubber	160	130	100
Sewer Plant	180	150	100
School Admin. Building	160	120	100
Aurora	115	100	100
Adams City	135	130	100
Englewood	135	120	100
Cherry Creek Dam	75	75	54
Lakewood	90	85	100
Arvada	150	150	100
Golden	85	80	100
Rocky Flats	65	60	54
Edgewater	NA	NA	NA
Westminster	120	95	100**
CARIH	120	100	100
Centennial Wells	105	80	100**

the eighteen sites. The data indicate that the annual standard is violated at most of the sites at all times. The two exceptions are the Rock Flats and Cherry Creek Dam sites.

SAI model results for particulates show that violations of the applicable standards will occur throughout the region in all analysis years. In fact, levels in excess of twice the federal standard (Figure 3-12)are prevalent and become steadily worse through the year 2000. Denver's particular problem is auto-related (55 percent)--much of it enters the atmosphere in the form of "re-entrained" dust and sand from winter road maintenance operations and unpaved roads. But only a small portion of the auto-related problem is caused by particles released directly from the automobile, such as lead or tire particles (<10 percent). Construction and stationary sources account for much of the remainder.

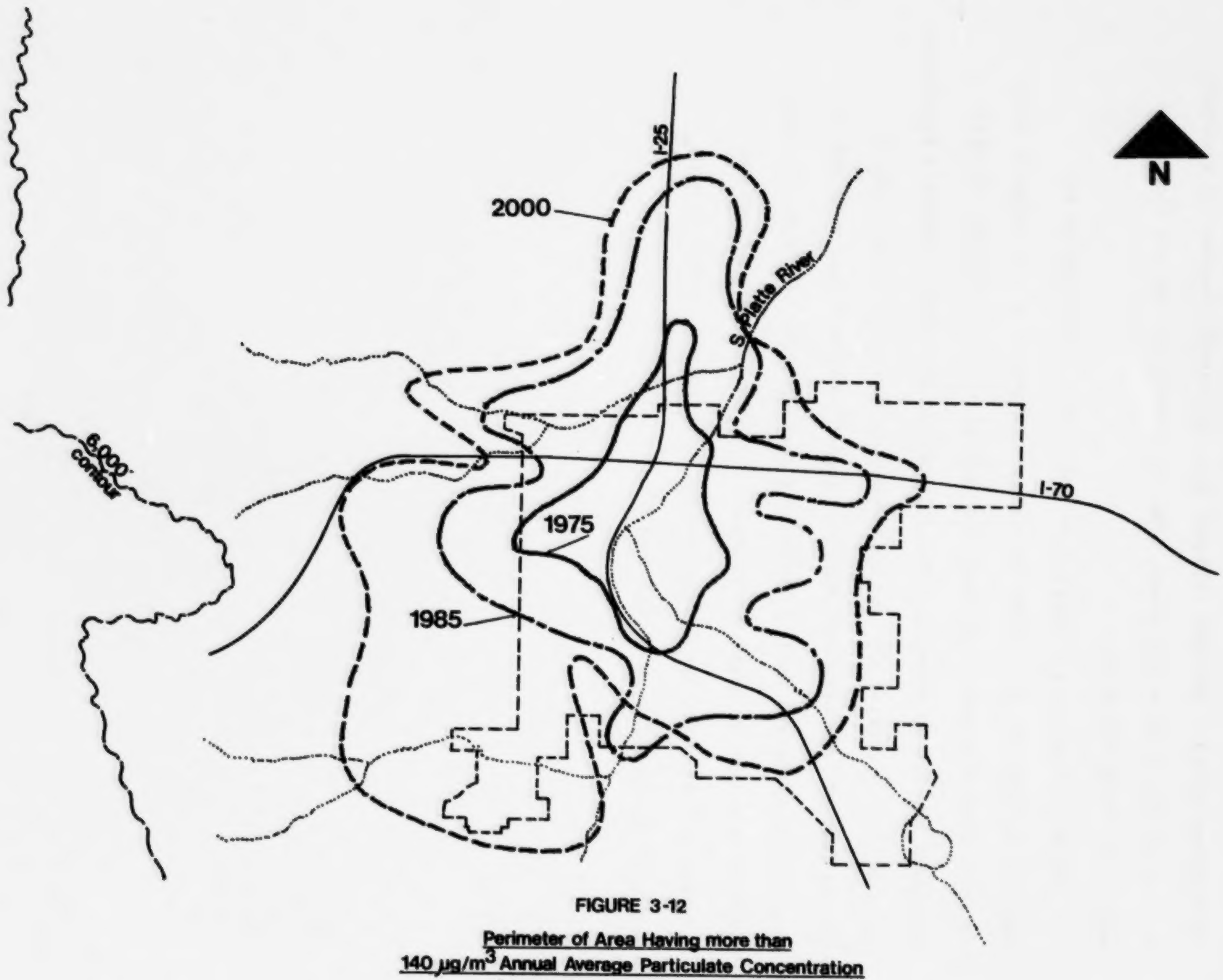

N
2000
1975
1985
I-25
I-70
S. Platte River
6,000' contour

FIGURE 3-12

Perimeter of Area Having more than
140 μg/m^3 Annual Average Particulate Concentration
(Applicable Standard is 45 μg/m^3)

SUMMARY

A summary of data describing Denver's air quality pollution problem is shown in Table 3-9. As indicated in the preceding descriptions, these numbers are based on measurements at a limited number of sites and on the results of a complex modelling process requiring numerous assumptions (Reference Appendix G). Although it is generally agreed that the Denver data are as good as or better than those of most other metropolitan areas, it also is acknowledged that the specific numbers should be treated with caution.[1]

1) The Denver area is expected to exceed the national ambient air quality standards for major auto related pollutants well beyond the federal deadlines. According to one regional air quality modelling effort, the CO one-hour standard should be attainable by 1985, and Denver will come close to the eight-hour standard by 1990. However, ozone, NO_2, and particulate standards are unlikely to be reached at any time in the foreseeable future unless additional controls are implemented.

2) There is lack of a consensus on the importance of the air quality problem in Denver, with sizeable support for transportation control on the one-hand, and considerable doubt about whether there actually is a problem on the other.

---

[1] As discussed in Appendix H, there are similar uncertainties about the health implications of air pollution. Knowledge of the health effects is based on a limited number of studies often involving short-term exposure to high levels of pollutants rather than longer-term exposure to levels more likely to occur in an urban setting; some of these studies have been open to criticism on their technical quality, as well. Although a National Academy of Sciences review of the air quality standards found them supportable (6), it is understandable why there is continuing debate over their effectuation.

TABLE 3-9

Summary Of Denver Air Pollution Facts

POLLUTANT	Ambient Standard (ppm)	BASIS FOR STANDARD	1975		1985		2000		% of Emissions by Source Category		
			% max. value* above standard	area of violation (sq. mi.)	% max. value above standard	area of violation (sq. mi.)	% max. value above standard	area of violation (sq. mi.)	direct auto emissions	other highway related emissions	other sources
CO	35 9	one hour eight hour	93 244	28 219	~0 79	2 61	0 1	0 16	73	26	1
HC	.24	three hour	NA	NA	NA	NA	NA	NA	55	26	19
NO	NA	NA	NA	NA	NA	NA	NA	NA	32	15	53
NO_2	.05	annual average	12	2	32	19	42	23			
Oxidants	.08	one hour	76	471	25	385	21	436	NA	NA	NA
Particulates	45**	annual average	400	All	536	All	614	All	~10	~45	~45

*second worst day of analysis year

**expressed in $\mu g/m^3$ rather than ppm

REFERENCES

(1) Strabala, Bill, "Cars Push Denver Pollution Beyond Level in L.A.," The Denver Post, July, 1977.

(2) Air Quality, Noise and Health, Report of a Panel of Motor Vehicle Goals Beyond 1980, prepared by Panel on Air Quality, Noise and Health, prepared for ERDA, DOT, FEA, NSF, March,1976.

(3) "Denver's Brown Cloud, Current Developments," Environment Reporter, 1977, p. 1694.

(4) Colorado Division of Highways, Air Quality Assessment Statement CY-1976, prepared for the Joint Regional Planning Program, December, 1976.

(5) Williamson, Samuel J., Fundamentals of Air Pollution (Reading, Massachusetts: Addison-Wesley Publishing Co.), 1973.

(6) National Academy of Sciences, National Academy of Engineering, Air Quality and Automobile Emission Control, "Volume 4 - The Costs and Benefits of Automobile Emission Control," U.S. Senate, 93rd Congress, 2nd Session, Committee Print, Committee on Public Works, September, 1974.

CHAPTER 4

VEHICLE EMISSION CONTROLS

INTRODUCTION

Unlike the other measures included in the Denver TCP, which are oriented toward changing travel behavior, the vehicle emission controls are intended to reduce the emissions per vehicle, either by changing the air pollution control technology on in-use vehicles or by inspecting and maintaining vehicle engines and existing pollution control devices.[1]

Federal Motor Vehicle Emission Control Program

Four groups of vehicle model years mark important milestones in the federal vehicle control program:

1) Pre-1968 model year vehicles had no exhaust emission controls;[2]

2) 1968-74 mode year vehicles incorporated a sequence of engine modifications aimed at reducing exhaust and evaporative emissions;[3]

3) 1975-76 model year vehicles are equipped with catalytic converters for exhaust emission control;

4) 1977 model year vehicles are equipped with catalytic converters and must meet federal emission standards at the point of sale. However, 1978-83 model year vehicles are exempted from this requirement by the 1977 Amendments to the Federal Clean Air Act.[4]

---

[1] Throughout this chapter the term vehicle refers to light duty motor vehicles defined as passenger vehicles seating 10 of fewer passengers and trucks with a gross vehicle weight of less than 8,500 pounds.

[2] Crankcase emission controls (e.g., "open" positive crankcase ventilation (PCV) systems) were introduced with the 1963 model year (1962 in California).

[3] These modifications included leaner mixture carburetor calibration, "closed" PCV systems, air injection and exhaust gas recirculation. This series of engine changes began to be introduced with the 1966 model year in California.

[4] The amendments do require manufacturers to develop instructions on appropriate engine adjustments for high altitude use and to meet standards at the point of sale beginning with the 1984 model year.

The issue of whether vehicles meet emission standards at the point of sale is particularly important for developing vehicle control measures for the Denver AQCR. As mentioned above, the 1977 model year vehicles are the first automobiles required to meet federal emission standards at the point of sale. Pre-1977 vehicles (and now 1978-83 model year vehicles) only had to meet standards at the point of manufacture; at Denver's altitude, 5,300 feet about sea level, vehicles emit approximately 50% more HC and CO than the same vehicle at sea level. For NO_x the effect is the opposite. An automobile at Denver's altutide emits approximately 50% less NO_x than the same vehicle at sea level (1). The point of sale for high altitude areas has been defined as 4,000 feet above sea level for the purpose of vehicle testing.

Each of the groups of vehicles listed above has faced increasingly stringent federal exhaust emission standards and has been equipped with different pollution control technology. As a result, the vehicle control strategies which are appropriate for each group of vehicles in Denver varies to some extent. For example, pre-1968 vehicles could be retrofitted with a variety of pollution control devices which have been installed on later model years, while high altitude modification kits could be installed as additional emission controls on the 1968-74 and the 1975-76 vehicles.

While differences in pollution control devices suggest different strategies for different classes of vehicles, it is a well established fact that exhaust emissions from all vehicles increase with age and use. Thus an inspection and maintenance program could potentially be applied to all vehicles.[1]

---

[1] For pre-1968 vehicles emission inspection standards would be difficult to set and a mandatory maintenance program might be more appropriate.

Two other factors which can influence the design of vehicle control measures or require modifications in the measures over time are vehicle fleet turnover and the development of new engine and pollution control technology. For the Denver region (and nationally) the entire vehicle fleet is replaced every 13 to 15 years and thus the composition of the in-use vehicle population is constantly changing (16,28). As a result, control measures targeted at specific classes of vehicles (in terms of model years) may become obsolete after a number of years. For example, by 1979 it is estimated that less than 6% of the Denver vehicle fleet will consist of pre-1968 model year vehicles (16).

There is considerable uncertainty associated with potential changes in engine and pollution control technology in response to future changes in federal emission standards. At the current time it is expected that the catalytic converter will continue to be the primary exhaust emission control device on light duty motor vehicles at least until the mid-1980 model years (5,29). However, at this time there is very little data on the performance and deterioration of catalytic converter-equipped vehicles which are certified for sale at high altitudes (e.g., 1977).

The EPA considers inspection and maintenance of in-use vehicles to be an important part of the overall federal emissions control program. The Federal Clean Air Act specifies exhaust emission standards for new automobiles and requires that pollution control devices must operate effectively for the useful life of a vehicle defined as 50,000 vehicle miles.[1]

---

[1] However, the performance warranty that pollution equipment operate correctly throughout the useful life of a vehicle can only be required if adequate test facilities are available and the vehicle owner is subject to some sanction under state or federal law. Such a sanction could be a fine or suspension of vehicle registration for a vehicle in non-compliance with the requirements of a state I/M program.

However, the federal law does not specify any controls to deal with the deterioration of in-use vehicles, vehicles over the 50,000 mile limitation, or tampering with pollution control devices.[1]

To address these "gaps" in the federal emission control program, EPA has encouraged states, including Colorado, to implement vehicle control measures, and specifically I/M programs. In addition, EPA has threatened to order that I/M programs be implemented if states refuse to take action.[2]

The 1977 amendments to the Federal Clean Air Act specify that any air quality control region which does not meet the NAAQ standards by 1982 must "establish a specific schedule for implementation of a vehicle emission control inspection and maintenance program."[3] Similarly, states which want the authority to require that EPA and manufacturer approved high altitude adjustments be made on new cars after December, 1981 must have instituted an I/M program and still be in violation of national standards.[4]

Vehicle Emission Control Measures in the TCP

The vehicle control measures included in the Denver TCP were:

1) retrofit for pre-1968 vehicles;
2) high altitude modification for 1968-74 vehicles; and
3) semi-annual inspection and maintenance.

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[1] While there are federal penalties associated with tampering, without inspection of in-use vehicles no enforcement is possible.

[2] Representatives of the EPA Region 8 office made such threats a number of times during the deliberations on the initial I/M legislation prepared in Colorado in 1975. More recently, the new EPA administrator warned the Connecticut legislature of the possibility of a federally mandated I/M program (Boston Globe (5/1/77)).

[3] Section 172(b)(11).

[4] Before January, 1981 this authority is available to all high altitude states.

At the time the TCP was promulgated in 1973, pre-1968 vehicles accounted for approximately 45% of the Denver vehicle fleet and were probably responsible for an even higher percentage of total exhaust emissions in the region since they had no exhaust emission controls (2).[1] Air bleed retrofit was selected from a range of retrofit options that were considered for both pre-1968 and 1968-74 vehicles. The choice of the air bleed option was primarily due to cost effectiveness considerations. The estimated cost in 1973 was 35 dollars (3). While the modifications reduce both HC and CO exhaust emissions they are most effective in reducing NO_x emissions.[2]

High altitude modification and tune-up for 1968-74 vehicles was aimed at compensating for the effect of high altitudes in increasing CO and HC exhaust emissions. The modifications would include changes to the carburetor and engine idle parameter adjustments. The estimated cost of these changes in 1973 was 20 dollars (3).

The inspection and maintenance program was not limited to any particular model year vehicles. If a loaded test was used the measure could reduce HC, CO, and NO_x emissions while an idle test could be effective only for CO and HC.

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[1] While newer vehicles accumulate more annual mileage, this factor is offset in this case by the higher initial emissions of pre-1968 vehicles and 5 or more years of emission rate deterioration.

[2] Air bleed to the intake manifold reduces HC and CO emissions but can increase NO_x. However air bleed in conjunction with exhaust gas recirculation or vacuum spark advance disconnect also reduces NO_x emissions.

IMPLEMENTATION OF VEHICLE EMISSION CONTROLS

Before discussing the implementation experience with the vehicle control measures in the Denver TCP, a number of observations should be made. First, the vehicle control measures represent the only mobile source controls, except for the Regulation 9 carpool program, for which the Department of Health has the primary implementation responsibility once legislative authority has been obtained. Thus a key focal point in analyzing the implementation of vehicle controls is the relationship between the Department of Health and the state legislature. Other state, regional, and local agencies with transportation planning, implementation, or operating responsibilities have played very peripheral roles in implementing vehicle controls.

During the period from 1973 to present the Department of Health and specifically the APCC and the APCD have been involved in a number of highly visible political controversies involving the state legislature. While some of these controversies have been directly related to vehicle control measures, others have concerned stationary source regulations, other transportation issues (e.g., I-470), APCD internal staff conflicts, and APCD staff qualifications. As a result, in assessing the implementation experience of vehicle controls and particularly inspection and maintenance, it is difficult to separate the legislature's reaction to vehicle controls from its broader concern with the entire air pollution control program of the APCC/APCD.

A description of the APCC and APCD roles in a number of issues is contained in Chapter 2. This section focuses on vehicle emission controls and only makes reference to some of the other controversies which have probably influenced the implementation of an I/M program.

Legislative History

Soon after the creation of the APCC, an Advisory Committee on Motor Vehicle Emissions was formed to assist the Commission in developing a vehicle control program. Members of the committee represented a broad spectrum of interests including new car dealers, petroleum retailers, the garage and service industries, and a range of consumer and environmental groups. In early 1973, the committee was instrumental in developing and lobbying for the passage of Senate Bill (SB) 393.

The key provisions of the bill were the establishment of a continuing source of funds for the APCD motor vehicle emission control program and a mandate that by December 1, 1973 the Department of Health make joint recommendations to the governor and legislature on a vehicle control program, including any training programs (e.g., for inspectors or mechanics) and consumer protection measures required.[1] The recommendations were to be based upon a pilot testing program and other studies for which the bill appropriated $381,000 from general revenues.

The major recommendations were:

1) phased implementation of an idle emissions inspection and maintenance program operated by the state or by a contractor through a franchise arrangement with the state;[2]

2) further study of exhaust gas analyzers prior to implementation of an I/M program;

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[1] The funding for the APCD motor vehicle emission program is provided by placing 30¢ of the fee collected for the state's safety inspection into a special account in the state highway fund. SB 393 also established the authority of police to fine motorists operating vehicles emitting visible exhaust pollution. The fine was set at $25.

[2] The report also recommended that a mandatory maintenance program not be substituted for I/M since its cost effectiveness would be lower (i.e., many vehicles not needing maintenance would be subject to a mandatory tune-up).

3) further study of air bleed/exhaust gas recirculation retrofit for both pre-1968 and 1968-1972 vehicles;

4) no further consideration of high altitude modification kits due to installation problems and resulting low effectiveness;

5) implementation of certain high altitude engine parameter adjustments if they are consistent with vehicle warranty constraints.

It should be noted that the preparation of the Denver TCP proceeded parallel with the conduct of these pilot studies and did not reflect all of the results of these studies. In fact, to some extent (i.e., with respect to high altitude modification), the TCP promulgated in November, 1973 was made obsolete by the results of pilot studies published one month later.

After consideration of the findings of the pilot studies, the legislature requested further study of various aspects of the recommended vehicle controls. During the next year further studies were conducted and the Advisory Committee and the APCD developed the first I/M bill to be submitted to the legislature.

Inspection and Maintenance and Retrofit

Early in 1975 a bill to implement an inspection and maintenance and retrofit program was submitted to the Senate. The major provisions of the program were:

1) inspection and maintenance for 1968 and newer vehicles beginning in 1977 in 8 counties in the Denver area.[1] The fee would be $5.00.

2) the I/M program would be state operated with one voluntary station open in early 1975 and 35 additional stations to be constructed in 1976.

3) retrofit (air bleed/EGR) for 1968-74 vehicles with the cost, including installation, not to exceed $45.

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[1] The counties were Adams, Arapahoe, Boulder, Clear Creek, Denver, Gilpin, Douglas, and Jefferson.

4) an appropriation of 1.06 million dollars to begin implementation of the program.

During the Spring of 1975, while hearings on the bill were in progress, it became unclear whether an adequate supply of retrofit devices would be available. Several manufacturers claimed the potential market was too small to interest them and there was adverse reaction to giving all the retrofit business to one individual who claimed to have sufficient surplus California devices to supply the entire program. In addition, concern was raised over the equity of requiring owners of seven year old vehicles to pay the costs of retrofit.

While some concerns were being raised about the retrofit portion of the program, a dispute over the benefits claimed for the I/M program led quickly to the killing of the entire package. The conflict began when the benefits claimed for the I/M program by the APCD in a report to the legislature were considered very optimistic by a newspaper reporter. It appears that the benefits claimed as ambient reductions in motor vehicle related pollutants were actually reductions in tailpipe emissions. This mistake resulted in an overestimate of benefits from I/M, especially for hydrocarbons. When the APCD retracted the original benefit estimates, the proponents of the bill were put on the defensive. In the face of growing criticism, the chairman of the APCC along with the directors of the Department of Health and the APCD recommended that the bill be killed. The Senate committee quickly obliged. As a result of internal staff conflicts within the APCD, which became apparent when this issue arose, the governor called for an investigation of the Division.

Inspection and Maintenance: Contractor Operated

During early 1976, the Governor's Ad Hoc Committee on Motor Vehicle Emissions, the successor to the Advisory Committee, together with the APCC, drafted and submitted another bill to implement an I/M program.[1] The retrofit portion of the program was dropped due to the concerns cited earlier. The major provisions of the program were:

1) inspection and maintenance for 1968 and newer vehicles with stations operated by a private contractor under a franchise arrangement;

2) the program was to begin in 1978 with mandatory inspection and voluntary maintenance. Mandatory maintenance was to be phased in during the following year.

While this version of an I/M program was passed by the House Transportation Committee, it was killed before any discussion on the floor of the House. The service industry strongly opposed the provision for contractor operation. In addition, the credibility problem created by the previous controversies over the effectiveness of an I/M program and the impacts of I-470, coupled with the legislature's traditional concern with any expansion of state government programs, contributed to the defeat of the legislation.

Current I/M Legislation

In late 1976, after further studies had been conducted by the APCD on catalytic converter equipped vehicles, the APCC and the Ad Hoc Committee developed the third version of I/M legislation. The major provisions of

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[1] After the submission of this bill, staff conflicts within the APCD surfaced on another controversial topic - projecting the air quality impacts of I-470. This conflict became public when the Chief of the Mobile Source Section challenged, before a legislative committee, the position of the Health Department, the APCD director and other APCD staff on their claim that construction of I-470 would increase air pollution in the Denver AQCR. Though the Health Department's position on I-470 was never proved to be invalid, the growing controversy and continued criticism of the APCD led to the resignation of the director of the APCD in October, 1975.

Senate Bill 231 were:

1) an annual inspection and maintenance program for 1977 and later model year vehicles in a nine county area starting in 1979;[1]
2) an idle test decentralized in private garages with state operated referee stations for consumer protection.

The bill was patterned after the legislation which created the vehicle safety inspection. The Department of Revenue, which operates and enforces the safety program through the Motor Vehicle Division, would be responsible for issuing station and inspector licenses, issuing inspection stickers to garages, and enforcing the program.

The major differences between SB 231 and earlier proposals were the placement of the program in the network of existing private garages and the exemption of 1976 and earlier model years. The use of private garages was an attempt to make the package more acceptable to both the legislature and the local service industry. A key factor in placing the program in private garages was evidence that "idle" tests were suitable for catalytic converter equipped vehicles eliminating the need for expensive dynamometer equipment. In addition, positive results from a mechanic training program at Colorado State University also may have helped to convince the APCC that a private garage run program could be effective.

The program was restricted to 1977 and later model years because:

1) elimination of older vehicles would reduce the concerns about the equity of the program (older cars would need more maintenance) and would require dealing only with vehicles having the same primary exhaust emission control (e.g., catalytic converter).
2) The 1977 model year represented the first vehicles subject to

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[1] Counties are Adams, Arapahoe, Boulder, Denver, Douglas, El Paso, Jefferson, Larimer and Weld.

the point of sale requirement and would eliminate the argument that I/M was required only because the manufacturers were failing to produce vehicles which could perform at high altitudes.[1]

3) While the APCD sponsored testing program on 1975 model vehicles suggested I/M would maximize the effectiveness of the catalytic converter, little data were available on the performance of the 1977 model year, thus reducing the risk of the controversies over data accuracy which had plagued earlier proposals for the program.[2]

The initial positive reaction to SB 231 by the service industry and environmental groups encouraged its sponsors and there was guarded optimism that an I/M program would finally win legislative approval. No groups publicly opposed the program, although some legislators voiced concerns about the inconvenience and cost to the public, the creation of another bureaucracy (e.g., DOH and DOR personnel involved in operation and enforcement), and APCD credibility.

In May, 1977, SB 231 passed the Senate where approval was expected to be more difficult to obtain. However, opposition to the bill developed in the House and an amendment was passed which essentially reduced SB 231 to a proposal for further study. A compromise was developed and the resulting SB 231 was passed by the legislature in June, 1977.

The version of SB 231 that passed delayed the start of the program until January, 1980, and required that legislative approval for the proposed idle test standards be obtained by July 1, 1979. The changes reflected the reluctance on the part of the legislature to give the APCC and the APCD a free hand in setting the standards and regulations which will govern the program.

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[1] This was prior to the passage of the 1977 Amendments to the Federal Clean Air Act which delayed the high altitude requirement until the 1984 model year.

[2] The opposite position also could be argued in some cases with plausibility, but was not taken at this time in Colorado because of the nature of I/M's legislative history.

Reacting to current public discussion and media coverage of Denver's air quality problem, the legislature considered several changes to SB 231 during the Spring of 1978 to make the program more stringent. After much debate, amendments eventually passed which moved up the starting date for I/M to August, 1978 and included 1972 and later model year vehicles. However, the bill as passed also transferred all responsibility for administering, operating and enforcing I/M to the Department of Revenue and would, as well, remove most other assigned responsibilities and technical support staff from the Air Pollution Control Commission.

The Governor has expressed support for implementing I/M faster than originally authorized and for covering more model years, but was not willing to support the re-assignment of I/M responsibilities and vetoed the bill as passed. Both the DOR and the APCD were concerned, as well, about placing vehicle inspection and maintenance completely within DOR because of the lack of the required technical expertise at this time. The Governor's veto subsequently was upheld by the legislature, and he has indicated that, if reelected in November, 1978, he will issue an executive order moving the program's starting date to March, 1979.

Agency Involvement and Responsibility

This section presents a brief summary of the involvement of key agencies or groups in the development of the I/M program specified in SB 231 and their responsibilities, if any, in the implementation and operation of that program.

Air Pollution Control Commission

The APCC is clearly the group which has taken the primary responsibility for developing the proposed I/M program. Passage of an I/M bill has been the Commission's first priority for the past few years and represents the major mobile source control measure for which the APCC and the APCD will have the primary implementation and operation responsibility unless the current bill is amended.

While the APCC and the APCD have worked together closely on all of the versions of the vehicle control legislation submitted to the legislature, the two groups have often had different opinions on the appropriate design of an I/M program. Key members of the APCC involved in the development of SB 231 favored a loaded test and centralized (e.g., state or contractor operated) program, but were willing to accept the idle test in private garages recommended by the APCD.

The I/M program has been a very visible and at times politically controversial issue. Because the program is closely identified with both the APCC and APCD, APCD internal staff conflicts and controversial stands on other issues (e.g. I-470) have undoubtedly hampered implementation efforts.[1] During the hearings on SB 231, the APCC took the lead in lobbying for the bill and APCD staff by design had little direct contact with the legislature.

SB 231 grants the authority to the APCC for establishing rules and regulations concerning:

1. procedures for inspecting vehicles
2. training and qualification programs for state-employed inspectors and investigators
3. operation of referee inspection stations
4. testing and licensing of inspectors
5. approval, calibration, certification and operation of test equipment
6. emmission standards (subject to legislative approval)
7. approval and certification of applicants for licenses

As mentioned earlier, the legislature is considering transferring all of these responsibilities to the Department of Revenue.

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[1] Naturally adverse reaction to the APCC's involvement in other pollution control efforts also may have affected I/M implementation efforts.

Air Pollution Control Division

The APCD has also played an important, although less visible, role in developing the program embodied in SB 231 and will provide the staff to implement many of the APCC regulations listed above. In contrast to the previous I/M proposals, when APCD staff participated in legislative testimony and lobbying, the APCD role with respect to SB 231 has been primarily providing technical information and recommendations to the APCC and in drafting a set of detailed regulations on how the proposed I/M program would be operated.

In addition to providing the technical information required by the APCC to develop the regulations for implementing and operating the I/M program, the APCD will operate the referee inspection stations and monitor other aspects of the program. Currently, the APCD operates a test facility at Aurora and a mobile test unit. The APCC and the APCD have also been instrumental in developing the Colorado State University mechanic training program which may be a crucial determinant of the success of an I/M program. Again, it should be noted that the legislature is currently reconsidering all of APCD's responsibilities for I/M and the vehicle emission research program.

Department of Revenue

While concerns about the effectiveness and enforcement of the safety inspection were raised during the legislative deliberations on SB 231, it is generally agreed by both the APCC and APCD that involvement of DOR in the I/M program was important for generating support. This is consistent with the legislature's Spring, 1978 proposal to transfer the entire I/M program to DOR. The DOR has experience in administering and enforcing a vehicle inspection program and under SB 231, as originally passed, has been given the authority to:

1) issue or revoke licenses for stations and inspectors;
2) supervise the activities of licensed stations and inspectors, including inspection procedures and record keeping;
3) conduct hearings on violations of regulations of DOR or the APCC;
4) adopt regulations for
    - issuance and use of inspection stickers
    - enforcing APCC regulations
    - facility inspection prior to licensing
    - fleet vehicle licensing
    - scheduling of vehicles for inspection

Though DOR was not enthusiastic about receiving these additional responsibilities, there appears to be a good, and improving, working relationship between DOR and DOH. The DOR is reportedly not in favor of assuming all of the responsibilities for administering, operating, and enforcing the I/M program as currently being considered by the legislature.

Environmental Protection Agency

EPA participates in the deliberation of the APCC's Advisory Committee on Motor Vehicle Emissions and the Ad Hoc Committee and has been an important source of technical information for the APCC. In addition, both EPA's Washington office and the Region 8 office have provided significant funding to Colorado State University for the development of mechanic training courses.[1]

However, due to EPA's involvement in a number of controversial issues in the Denver area and the adverse reaction on the part of the legislature to any suggestion that unless the State implemented I/M then EPA would mandate it, the EPA had little involvement in the development of, or lobbying effort for, SB 231. The APCC felt the prospects for SB 231 would be improved if EPA was not involved. This assessment was concurred with by representatives of EPA Region 8 and the EPA Washington office.

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[1] While much of this funding was for courses to be given outside the Denver AQCR, EPA's participation helped create a unique resource at CSU which could be used for the Denver I/M program.

Legislature

The legislature has clearly had a significant role in shaping the I/M program and still must approve the test standards before the program can begin. The current amendments being considered to make the program more stringent and place it under the control of the DOR were initiated by the legislature. Some of the opposition to I/M expressed during the Spring, 1977 legislative session reflected a reluctance to increase state spending and bureaucracy in general and a continuing skepticism about the APCC and APCD's data and credibility. In addition, however, several concerns were raised specifically about the proposed design of the I/M program.

The major questions raised were whether:

1) the public might be cheated by the private garage industry and face exorbitant maintenance costs;

2) the test equipment might be unreliable and fail vehicles that ought to pass and vice versa;

3) small garages which do not elect to participate in the program due to equipment cost might lose both maintenance and safety inspection business.

The committee and floor votes in both houses did not follow partisan lines but did split to some extent between urban and rural regions. While traditionally conservative legislators voiced the strongest opposition to I/M, some urban legislators also opposed the program on the grounds that any further charges assessed to low income families would be regressive and that mass transit improvements represented a more equitable alternative.

Governor's Office

While the governor has publicly supported previous I/M proposals, there was very little visible action on the part of the governor in support of SB 231. It appears that the administration was content to let the APCC take the lead in developing support for SB 231 in the legislature.

Other Groups

The other major groups that were active in lobbying for SB 231 were service industry representatives and environmental and consumer groups. The Colorado New Car Dealer Association was the service industry representative most active in lobbying for the bill while most of the other service industry representatives who participated on the APCC Advisory Committee, either supported the bill or had reservations but did not publicly oppose the program. Both the League of Women Voters and the Colorado Open Space Council (a coalition of environmental groups) supported and lobbied for the bill.

INSPECTION AND MAINTENANCE PROGRAM DESIGN

There are a number of basic design elements in an inspection and maintenance program which determine its overall effectiveness:

- vehicles covered
- inspection frequency
- inspection stations and inspectors
- inspection test type and equipment
- test standards/rejection rate
- inspection procedure
- fees and penalties
- funding
- enforcement
- mechanic training and maintenance
- consumer and hardship protection

This section provides a brief assessment of each of these elements for the Denver program, including a comparison of other I/M programs where appropriate. While detailed regulations for implementing the Denver I/M program have not been prepared to date, the legislation authorizing I/M specified many of the elements of the program. In addition, draft regulations prepared in early 1977 and studies performed for the APCD provide insights into the likely approach to other elements.

Vehicles Covered

The Denver I/M program as currently authorized will cover 1977 model year and later, light duty motor vehicles and will begin in 1980.[1] The legislature may move the starting date to mid-1978 and include 1974 and later model years. The definition of motor vehicle was carefully specified to avoid the problems created in Arizona where interpretation of a more general definition of vehicle made golf carts among other vehicles eligible for inspection.

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[1] These vehicles must have four or more wheels, be self propelled by liquid gasoline and manufactured primarily for the transportation of not more than ten people. Trucks weighing 8,500 pounds gross vehicle weight, or less, are also included.

The draft regulations written in early 1977 provided exemptions for emergency vehicles and it is likely that such an exemption will be provided. In addition, the law states that new vehicles are exempt from inspection for 12 months (after delivery or initial vehicle registration). The new car dealers were particularly concerned about getting an exemption for new vehicles in order to avoid a potential conflict between the manufacturers and dealerships about the responsibility for a new vehicle which does not pass inspection.

Because of the new car exemption, during the first year of the program (1980), it is estimated that approximately 37% of the vehicle fleet (380,000 vehicles) will be included in the I/M program. By 1985, 73% of the vehicle fleet (875,000) vehicles will be included in the program.[1]

Inspection Frequency

While the original TCP specified semi-annual inspection and maintenance, the proposed program will occur on an annual basis. Given engine deterioration rates, a six to nine month interval between inspections would result in higher reductions. This is particularly true for HC emissions which, after emissions related maintenance, deteriorate back to pre-maintenance levels more than twice as fast as either CO or NO_x (4). HC emissions reach pre-maintenance levels after about six months of normal use.[1]

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[1] There are a number of vehicle population projections for the Denver area. These projections are based on reference (2). If the program is amended to start in 1978 and cover 1974 and later model years, 34% of the vehicle fleet (333,000) would be covered in 1978 and by 1985 about 93% of the fleet (1,122,000 vehicles) would be covered.

The selection of an annual inspection cycle reflected primarily a concern for public convenience and cost.[2] A semi-annual program would require twice as much inspection system capacity to maintain the same average wait times. For a privately operated program, attracting more garages to participate would require raising the allowable fee.[3] It is interesting to note that there was significant public opposition to the recent shift of the Colorado safety inspection program from a semi-annual to annual basis. The primary concern was that the number of unsafe vehicles would increase.

There is no provision in the law to either require or prohibit safety and emission inspections from occurring at the same time. Regulations will probably give the motorists some discretion in this matter,although some service industry representatives supported combined semi-annual safety and emission inspections.

Inspection Stations and Inspectors

Under the proposed Denver I/M program there are three types of inspection stations:

1) Emission inspection stations: privately operating facilities offering inspection (though not necessarily maintenance) to the general public.

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[1] There is some disagreement over the deterioration rates of HC and CO after maintenance. A later section of this chapter discusses the issue further.

[2] Almost all existing I/M programs are on an annual cycle and some (e.g. Oregon) occur even less frequently.

[3] A survey of garages, dealerships, and service stations performing safety inspections in the Denver area suggested that the percentage of firms which would participate in the I/M program would triple (26% to 79%) if the proposed fee was raised from $4.00 to $8.00 (5).

2) Fleet emission inspection stations: the owner, lessee, or operator of a fleet of ten or more vehicles subject to I/M can, by meeting the same requirements as stations in 1) above, perform inspection and maintenance for fleet vehicles only.

3) State referee emission inspection stations: operated by Department of Health personnel these stations will perform consumer protection functions including reinspection of vehicles which fail the test and verification of the cause of rejection.

To be eligible to operate an emission or fleet emission inspection station,written proof that the proper facilities, equipment and staff are available will have to be submitted to the Department of Revenue (DOR). Inspectors will have to pass a qualifying test administered by the DOH prior to being issued a license by DOR. The law allows the DOH to develop a voluntary inspector training program.

While proposals for a centralized and state operated, or state franchised and contractor operated, I/M program failed to gain legislative approval, there is some feeling both in EPA and the APCC that centralized I/M programs are more effective. The major concern with decentralized programs operated by the service industry is the administrative burden associated with licensing and operating the program, enforcement, and consumer protection. Strict licensing and enforcement are felt to be critical for the development of an effective I/M program in the private sector (6).

Centralized approaches minimize the number of facilities, test equipment, and inspectors requiring licensing and supervision.[1] However state operated programs require significant "front-end" money to start the program and require the creation of a new bureaucracy, often a sore point with a state legislature. Contractor approaches don't require significant state funding but do eliminate a certain amount of flexibility to change the program's operating rules, test standards, etc., if contractor franchise rights and particularly revenues might be jeopardized. Either a contractor or state operated program may have additional lead time requirements due to the need to construct test facilities. An additional problem with centralized approaches is the potential for long wait times at inspection facilities. Lines at urban stations in New Jersey created a new occupation, "car sitters."

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[1] Most existing I/M programs are centralized and operated by the state (e.g., Oregon, New Jersey), a contractor (Arizona, California), or a municipality (e.g., Chicago, NYC Taxi and Limousine Commission).

Despite the attractions of a centralized program, there is some evidence that in states with decentralized safety inspections, there will be strong pressure for decentralizing emission inspections as well.[1] New car dealers and garages in Denver opposed both state and particularly contractor run programs. Proponents of a decentralized program cite the shorter wait times for the public and the need to rely on private garages in any case for maintenance. Thus, with a decentralized program the routine adjustments required by most failed vehicles can occur at the same time that the test is made. In addition, the existence of the facilities (and often the equipment) in the private sector often allows the program to begin more quickly. The projected budgets and fees for the Colorado program indicate that a decentralized program will not be significantly more expensive to the public than a centralized program.[2]

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[1] Like Colorado, Rhode Island has recently selected a decentralized program.

[2] A study for the APCD suggested that the costs to the public (fee and maintenance) from a state run program would be $11.62/vehicle and $12.45 for a private program (7). Current cost estimates are included in the next section of this chapter.

Test Type and Equipment

The Denver program will use an idle test for emissions inspection (e.g. vehicle is in neutral and idling during the test). Recent evidence has suggested that the idle test mode is quite reliable at identifying the 25 to 30% of the vehicles which are the worst polluters as determined by a loaded test(7). To a lesser degree, the idle test is correlated with the Federal Test Procedure (FTP) used by EPA for testing new automobiles (8,6). The FTP uses both hot and cold starts and is loaded and at idle for different portions of the test cycle.

Thus, if the objective of an I/M program is to identify the highest polluting vehicles only, an idle test using an exhaust gas analyzer is sufficient.[1] The major differences between the two tests for identifying the worst vehicles are cost, diagnostics, and identification of NO_x levels. The idle test equipment costs from $2000 to $3000, does provide valuable diagnostic information, but does not measure NO_x levels.[2] The loaded test equipment (dynamometer) costs from $8,000 to $10,000, provides much better and more detailed diagnostic information, and does measure NO_x levels.

Once an idle test was selected for the Denver program, concern was expressed about the ability of private garages to purchase the equipment.[3] However, representatives of independent garages, service stations, and new car dealers claimed the purchase price would not be a significant barrier to participation in the program. A survey of selected garages, service stations, and dealerships indicated that 32% of those facilities participating in the safety inspection program had analyzers. About 50% of the new car dealers had the equipment. There are about 1,250 facilities participating in the safety program including 117 dealerships (5). Currently major manufacturers (e.g., Marquette, Barnes, Champion, etc.) are encouraging use of analyzers as valuable equipment for tuning cars for both fuel economy and emission benefits.

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[1] Currently New Jersey and Oregon do idle tests while California and Arizona do loaded tests but in Arizona only an idle test must be passed with the loaded test used only for diagnostic purposes.

[2] Significant production of NO_x only occurs at high engine operating temperatures produced at high engine speeds (2500 RPM or greater in neutral).

[3] Selection of a decentralized program almost requires use of an idle test from an equipment cost point of view.

An additional concern expressed was whether variations in calibration from one analyzer to another,or for the same equipment over time,could result in a vehicle failing a test at one station (or point in time) and passing at another station (or passing at the same station a few days later). While equipment calibration is affected by heat, humidity, and vehicle temperature, it is expected that most equipment currently in garages will catch most of the 25-30% worst vehicles even though the absolute readings obtained would vary from analyzer to analyzer or over time (9).

The concern about test equipment increased when five manufacturers sent analyzers to the APCD and none of them passed the APCD's initial recommended accuracy specification. Garages which already had equipment were particularly concerned that their analyzers would not be certified. While the results of this test were seized upon by opponents of I/M, it does not appear that test equipment availability will pose a real problem.

Test Standards/Rejection Rate

As evidenced by the legislature's action requiring specific approval of the proposed inspection test standards, the level at which these standards are set (and hence how many vehicles fail) is one of the key determinants of the effectiveness of an I/M program. In addition, because the standards determine how many vehicles will fail the test (rejection rate), they may be a key factor in public reaction to the program. In a number of programs initial standards have been set very leniently (e.g. New Jersey) or the programs have been phased in with mandatory inspection and voluntary maintenance followed by mandatory I/M in an effort to encourage pre-test maintenance (e.g. Oregon, Arizona).

Naturally, prior to an inspection cycle it is impossible to predict precisely what rejection rate will result from a given set of standards. As standards are made more stringent, the rejection rate will increase while the average repair cost per rejected vehicle will decrease (i.e., the worst emitting vehicles will have the highest average repair cost and will be failed even with fairly lenient standards).

There is also some concern that constant test standards over time will result in an increasing rejection rate due to engine deterioration and changing fleet composition. However, experience with a number of existing programs suggests that increases in pretest maintenance can offset these factors and result in stable rejection rates (6).

Most existing programs have rejection rates in the 25-35% range. During the first year of the Arizona program (maintenance was voluntary), the rejection rate was 50%,while this year the target is 25%,and the actual rate may be lower due to pre-inspection maintenance. The New Jersey program is currently failing about 18% of the vehicles tested.

Further testing will be performed before standards and an estimated rejection rate are recommended for Denver. Earlier studies showed that the most cost-effective rate would be 30 to 40% (8).[1] Failure of either the HC or the CO standard will constitute failure of the test. While some ongoing I/M programs have set standards so that more vehicles will fail due to high emission of one pollutant (generally HC), it is likely that the standards will attempt to fail an equal number of vehicles for high CO or HC emissions with some number failing both standards. However, the maintenance performed to correct high emissions of one pollutant generally lowers the emissions of the other pollutant as well.

Inspection Procedure

While detailed operating procedures for the Denver program have not been approved by the APCC, several of the elements of earlier draft regulations are likely to be reflected in the operation of the program including:

- a vehicle can be brought to any emissions inspection station for initial inspection (not including fleet or referee stations);
- if the vehicle passes, a certificate of compliance sticker will be issued;
- if the vehicle fails, the vehicle can be taken anywhere for the necessary repairs. However, if the vehicle leaves the inspection site a certificate of denial sticker will be issued. Inspection stations will have to furnish a checklist of recommended repairs and adjustments.
- within a specified time period (ten days in the draft regulations), a vehicle must be repaired and reinspected. One reinspection at

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[1] For the analysis of I/M effectiveness contained in Chapter 11, a rejection rate of 40% is assumed.

the original inspection site is free.

- after initial inspection or reinspection a vehicle can be taken to a referee station to verify test results or the recommended maintainance. No fee will be charged at referee stations.

Fees and Penalties

The law authorizing the Denver I/M program states that the inspection fee is not to exceed $5.20. This fee, $5.00 of which will go to the inspection station, is in the range that is expected to attract participation of about 54% of the facilities now participating in the safety inspection program (5). There are a total 1250 safety inspection stations. Referee stations will not charge a fee.

The law also authorizes the Department of Revenue to suspend the registration of any vehicle in non-compliance. There is no exemption provided for a vehicle which repeatedly fails the test.

Funding

For each certificate of emissions compliance issued, the DOR will receive 20¢ of the $5.20 fee. These monies will be credited to a special account in the highway users tax fund and be used "only to cover the costs of administration and enforcement of the motor vehicle emissions activities" of the Departments of Revenue and Health upon appropriation by the legislature. The 20¢ fee should generate approximately $70,000 in 1980 and about $175,000 in 1985 (2).[1]

The I/M legislation also continues the 30¢ fee included as part of the safety inspection fee but specifies that these funds be used "to cover the cost of the motor vehicle emission control studies and training programs and administration thereof" by the Departments of Revenue and Health.[1] The 30¢ fee for each safety inspection currently generates about $600,000 per year since all vehicles are required to be inspected. There is currently about $1.2 million surplus in this account.

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[1] Estimates by DOR are slightly higher than these figures and are reported in the next section of this chapter.

Enforcement

The Department of Revenue, which administers and enforces the safety inspection program, has the responsibility for enforcing the I/M program including inspection of testing facilities and suspension of the registrations of violating vehicles. As mentioned previously, the involvement of the DOR in the I/M program was important to gain legislative approval, despite reservations about the effectiveness of the safety program and DOR's involvement may be broadened by amending SB 231.

While the Stationary Source Section of APCD has enforcement responsibility for the APCC's stationary source regulations and the Regulation 9 carpooling program, the type of enforcement required for the I/M program was felt to be sufficiently different (and more like DOR's safety program responsibilities) to warrant placing the enforcement of the program outside of the APCD. The Mobile Source Section of APCD, which will administer the DOH portion of the program, has no enforcement experience of any kind.

The draft regulations prepared earlier in 1977 required detailed record keeping and reporting on the part of the inspection stations. These requirements are likely to continue to complement on-site visits for enforcing the program.

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[1] Prior to the passage of SB 231 these funds were authorized to be used for the emission control "activities" of DOR and DOH. Again, it should be noted that the legislature is currently considering transferring all of the research and testing programs to the DOR.

Mechanic Training and Maintenance

A key to the effectiveness of the I/M program will be the ability of mechanics to take the test results for failed vehicles and perform the necessary repairs or adjustments. While some concern has been expressed about the potential for the public being deceived by the repair industry, the major problem is more likely to be a lack of understanding of emission controls and emission related repairs than a deliberate attempt to perform unnecessary repairs.[1] As a result, mechanic training has been an important part of the vehicle control program since 1973.

Soon after the passage of SB 393 in 1973, which provided 30¢ of each safety inspection to the emissions control program, development of a mechanic training program at Colorado State University (CSU) was begun. In the early stages of the program a 40 hour course for vocational education instructors was developed.

Subsequently a 12 to 16 hour course for mechanics was developed. Within the past two years approximately 1300 mechanics and vocational education students in the Denver area have taken the course even though for most mechanics the course must be taken at night or on their own time. Because the mechanic training course is quite short, the major objectives are to present the basic concepts of emission control, stress the use of manufacturers specifications and manuals, and describe the diagnostic capabilities of the exhaust analyzer.[2]

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[1] Service industry representatives admitted that there are a few disreputable garages and a high turnover in ownership in about 20% of the stations and garages due to poor quality work which gives the industry a bad image. One industry representative felt that state licensing of repair shops was desirable to develop quality control.

[2] CSU staff expressed the desire to lengthen the mechanic training course to 20 hours if mandatory certification is required as part of the I/M program.

While it is difficult to assess the effectiveness of the mechanic training, it does appear to have increased the use of exhaust analyzers for tune-ups. In one instance a dealer had acquired 7 analyzers in anticipation of the start of the I/M program but was not using the equipment in the interim until several mechanics at the facility took the CSU course.

To date the CSU program has received about $640,000 primarily from EPA's Washington and Region 8 Offices and the DOH. However much of the approximately $400,000 from EPA has been for conducting the instructor training course outside of the Denver area.

The actual maintenance that will be required on failed vehicles, in most cases (i.e., about 80% from CSU's experience), will consist of minor repairs and adjustments.[1] Often owners who experience driveability problems (e.g., stalling, loss of power, etc.) enrich the air/fuel mixture and adjust the spark timing. Many times the driveability problem is caused by improper driving habits and, in particular, not warming up the engine prior to driving. The leaner air/fuel mixtures needed for low emissions require a warm engine for the best performance.[2]

In addition to the more routine minor adjustments, both CSU staff and service industry representatives reported a relatively high level of tampering with pollution control devices. The most typical problems were disconnected air pumps or EGR systems and air cleaners with holes drilled into them.

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[1] The costs and distribution of repair types for test vehicles is provided in the next section.

[2] While changing the air/fuel mixture requires only a simple adjustment, rich mixtures can burn out a catalytic converter resulting in a major repair bill.

Consumer and Hardship Protection

The proposed I/M program reflects a concern on the part of the APCC and legislature with consumer protection. The program provides for referee stations specifically to provide recourse to motorists who question the results of a test at an emission station. In addition, stations will have to provide motorists with a recommended check list of repairs and adjustments if a vehicle fails and provide one free retest.

The original version of SB 231 had provisions for a hardship exemption for low income individuals and for owners of vehicles which repeatedly failed inspection and required excessive repairs to be brought into compliance.[1] However, both service industry representatives and members of the legislature objected to exempting any vehicles particularly,since the program, as originally passed, was expected to apply to 1977 and later model years. SB 231 as passed includes no hardship exemption.

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[1] The recommended exemption was for repair bills exceeding $75 or 10% of the blue book value of the vehicle (7).

EFFECTIVENESS AND IMPACTS OF I/M

While the final design of the Denver I/M program is not likely to be known until sometime in 1978, studies conducted by the APCD and others provide some indication of the likely impacts of the program. Because I/M appears to be the only vehicle control measure likely to be implemented over the next few years, impact estimates are provided only for this measure.

Effectiveness

All of the program elements discussed in the previous section will influence the ultimate effectiveness of the proposed I/M program. However, the factors which are most critical to assessing the likely impact of an I/M program are

- vehicle emission deterioration rates (both with and without I/M)
- percent of emission deterioration recoverable by I/M
- rejection rate (% of vehicles failed)

The first two factors are determined by the vehicle engine and pollution control technology and "normal" maintenance practices.[1] The rejection rate theoretically can be set at any level but must in practice balance the emission reduction gains from increasingly higher rates against increasing total maintenance costs and adverse public reaction.

While there are a number of sources which provide estimates of I/M effectiveness, it should be noted that it is still unclear which model years will be included in the Denver program. Currently there is very little data on the performance and deterioration of catalytic converter equipped vehicles at high altitudes (1975 and later model years). There is even less information on vehicles certified to meet federal standards at high altitudes (1977). Thus, the effectiveness data presented here must be viewed as somewhat tentative and subject to revision. However, while the range of estimates on I/M effectiveness is large, even the most pessimistic estimates suggest that an I/M program will have substantially greater benefits than any of the other measures included in the Denver TCP (cf. Chapter 11).

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[1] Assuming little or no tampering, "normal" maintenance reflects both the frequency that the vehicle is brought in for repairs and the quality of those repairs.

The data to be presented here are based on studies conducted for the APCD. The conclusions drawn from these studies in some cases are more conservative than current EPA estimations on the effectiveness of I/M.[1]

Deterioration Rates

Figure 4-1 shows the assumed deterioration rates for HC and CO emissions as function of age for 1977 and later model years developed in a study for the APCD (4).[2] At the beginning of year 1 the vehicles are assumed to meet federal standards at high altitudes.[3] For both CO and HC

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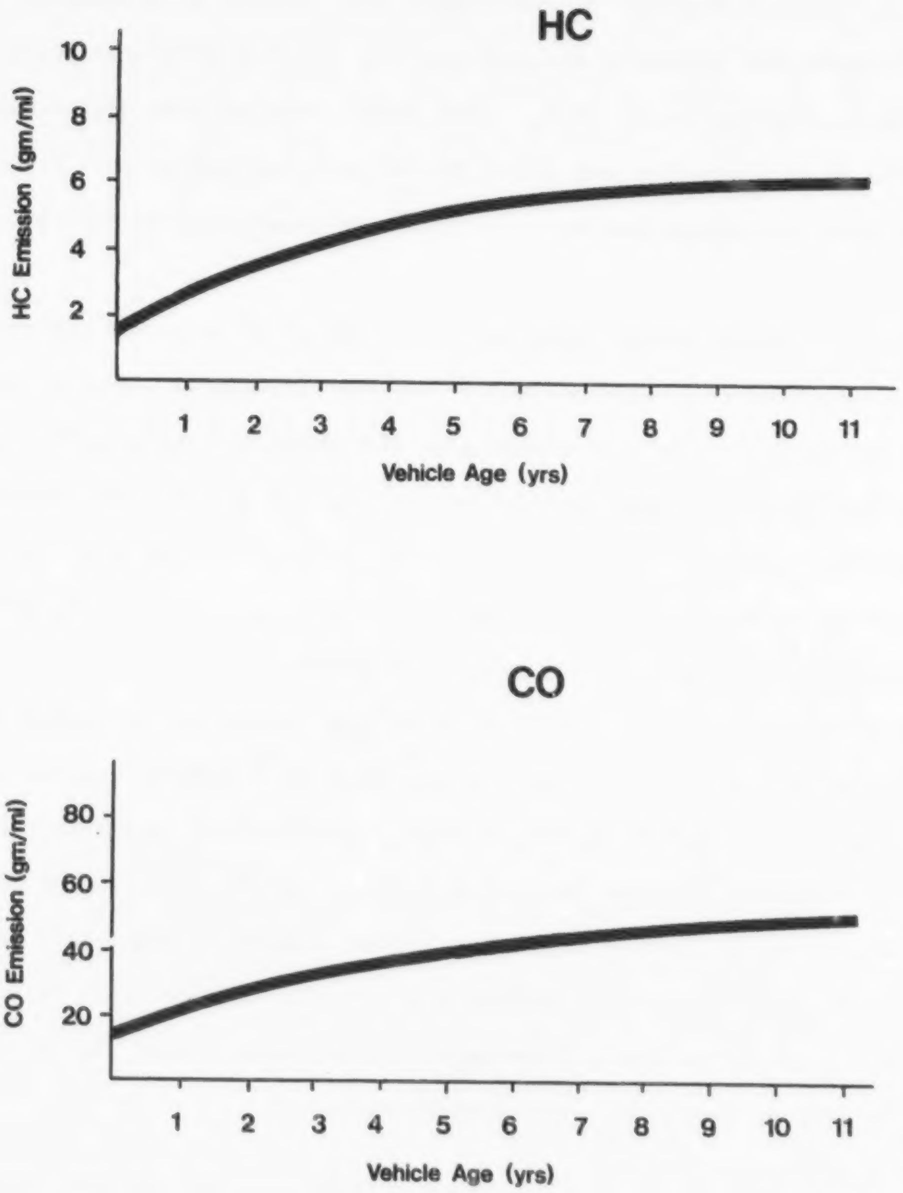
[1] To analyze the effectiveness of various TCP strategies in Chapter 11, EPA estimates of I/M effectiveness were used (10). EPA estimates that in the first year of an I/M program with mechanic training, reductions of CO and HC emissions are 39% and 22% respectively at a 40% rejection rate. By the eighth year of the program these reductions increase to 61% and 51% for CO and HC respectively. The average reduction over a vehicle's life are 40% for CO and 33% for HC. Naturally, if the I/M program is applied to less than the entire vehicle fleet, as in the case of Denver initially, these reductions would be less (see Chapter 11).

[2] The curves for 1982-85 model years had the same shapes but the intercepts were the proposed new emission standards of .41 gm/mi for HC and 3.4 gm/mi. for CO.

[3] Given the 1977 amendments to the Federal Clean Air Act, only 1977 model year vehicles are likely to meet standards at high altitude until the 1984 model year. While the shape of the deterioration curve for pre-1977 and post-1977 model years is likely to be similar to that in Figure 4-1, the initial emission values may be up to 50% higher.



Source (4)

FIGURE 4-1

Emission Deterioration Rates

deterioration rates begin to level off after about seven years. However, studies by both the APCD and the EPA suggest that initial deterioration rates for catalytic converter equipped vehicles are much more significant than were assumed initially (8,6). APCD studies suggest that approximately 30% of the HC deterioration and 15% of the CO deterioration is due to internal engine degradation and not recoverable by normal tune-up and repairs (11).[1]

Figure 4-2 shows typical profiles of the effect of an annual I/M program for both HC and CO emissions (4).[2] The top curve in each figure represents the deterioration rate assuming no I/M, while the lower curve represents that portion of deterioration not recoverable by I/M. The dashed vertical line represents the initial decrease in emissions for a failed vehicle after maintenance and the diagonal dashed lines represent emissions deterioration back toward the pre-maintained levels.

As the curves suggest, HC deterioration back toward the pre-maintained level occurs much more rapidly than CO deterioration. However, estimates on the time period required for HC to reach pre-maintained levels vary (10, 6). The APCD study on which Figure 4-2 is based estimated the period to be six months and that about 85% of the initial reduction of HC would be lost with an annual program. A semi-annual program would be about twice as effective for HC as an annual program. For CO about 25% of the initial reduction will be lost over a twelve month period.

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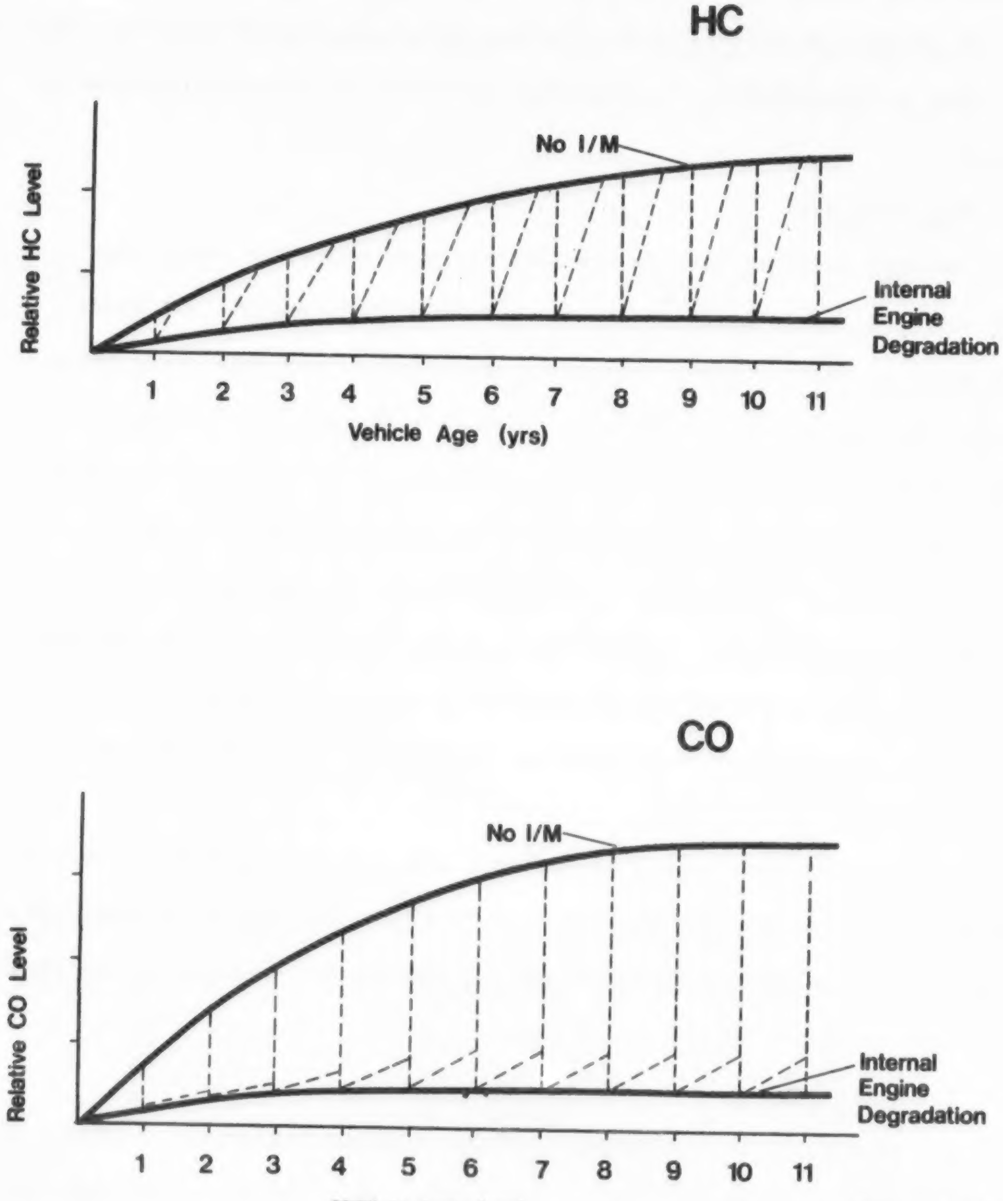
[1] Factors contributing to this degredation include ring and cam wear, valve leakage, air and fuel passage clogging and decreased catalytic converter efficiency.

[2] The curves were developed from data on 1968-74 vehicles and assumed to represent 1975 and later vehicles as well.



Source (4)

FIGURE 4-2

Deterioration Rates With Annual I/M

Thus, both from the point of view of the percent of deterioration recoverable by I/M and the deterioration rate after maintenance, it is clear that an annual I/M program is more effective in reducing CO emissions than HC. This is confirmed by virtually all estimates of I/M effectiveness reviewed.

Rejection Rate

The APCD obtained data on the percentage of emissions reductions achievable at different rejection rates from a study on 150 1975 model year vehicles (8). Table 4-1 presents the results from this study which suggest that only marginal gains in emission reduction are obtainable beyond a 40% rejection rate.[1] However, because all the vehicles tested were relatively new, the reductions possible from higher rejection rates will increase as the distribution of age for vehicles equipped with catalytic converters becomes wider. Nonetheless, other studies have confirmed that at rejection rates beyond 60% the decreases achievable begin to level off and that a 30% rejection rate provides 75% of the reductions obtained at a 50% rejection rate (12).

When cost of maintenance is combined with the information in Table 4-1, the cost-effectiveness curves presented in Figure 4-3 can be obtained (8). Almost all of the APCD reports presenting I/M benefit data during the past year have assumed a 40% rejection rate.

Effectiveness

The data in Table 4-1 suggest that the maximum achievable initial reductions (i.e., immediately after maintenance) at a 40% rejection rate are 24.6% for HC and 24.3% for CO. These estimates do not reflect any deterior-

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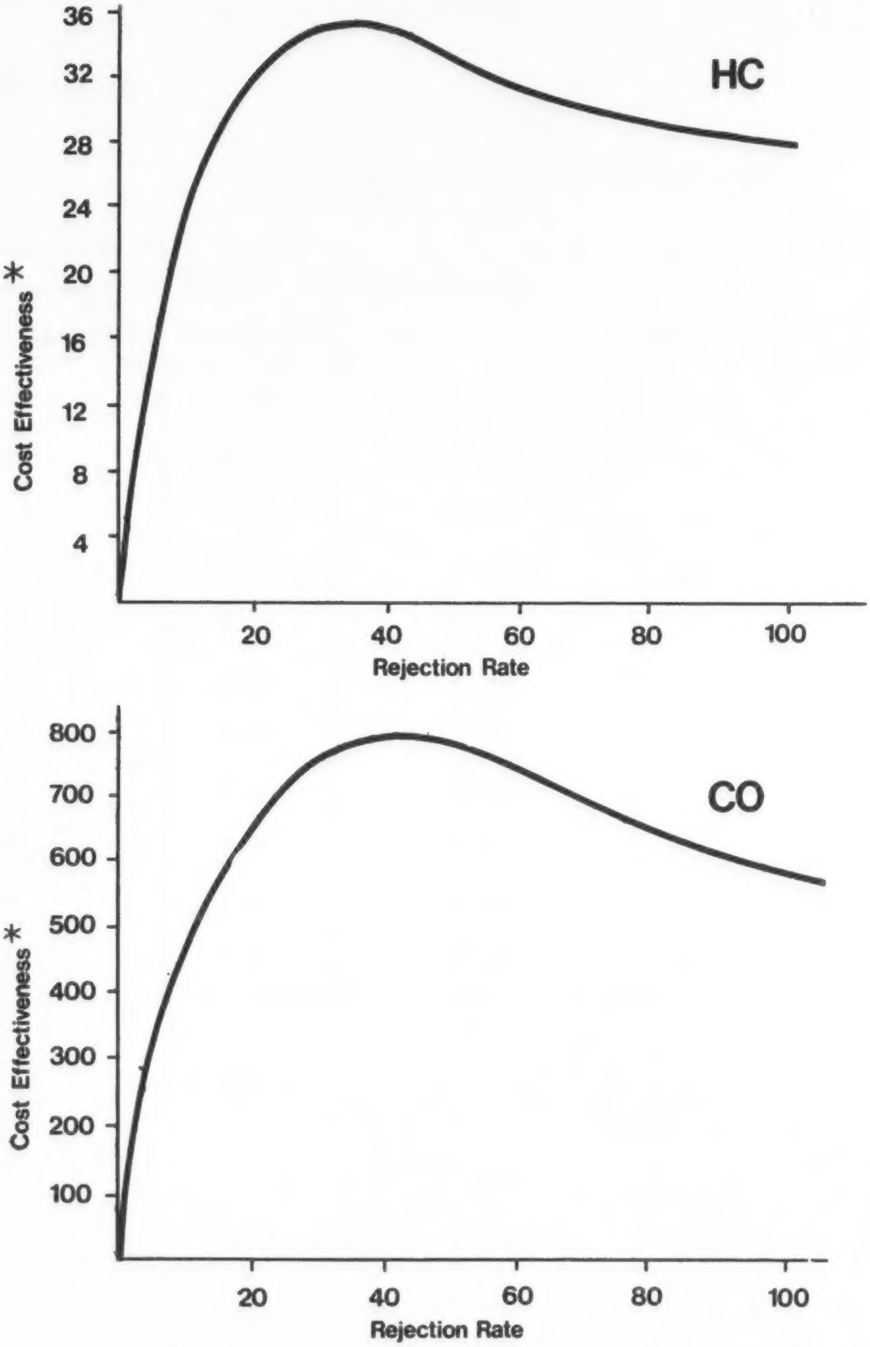
[1] The study utilized the ΔFTP test procedure and thus the reductions shown are maximum achievable initial reductions.

TABLE 4-1

Emission Reduction Versus Rejection Rate

Rejection Rate	Exhaust Emissions (gm/mile) HC Emissions	HC % Change from Base	CO Emissions	CO % Change from Base
Baseline	2.43	-	49.0	-
10	2.17	10.8	43.9	10.4
20	2.01	17.3	40.4	17.6
30	1.90	21.8	38.4	21.6
40	1.84	24.6	37.1	24.3
50	1.79	26.7	35.9	26.7
60	1.75	28.2	35.2	28.3
70	1.75	28.2	34.7	29.3
80	1.73	28.7	34.5	29.7
90	1.74	28.5	34.6	29.6
100	1.78	26.9	35.4	27.8

Source: (8)



Source (4)

* milligrams/mile/dollar

FIGURE 4-3

Cost Effectiveness Versus Rejection Rate ation back to pre-maintenance levels of adjustments due to tampering. Similarly, they do not reflect the potential cumulative benefits of an I/M program achievable when post-maintenance deterioration does not reach pre-maintenance emission levels. Such a cumulative effect would be obtained at least for CO based on Denver studies and potentially for HC based on other studies.[1]

Recognizing the uncertainty associated with many of these factors, the APCD estimated that initial (i.e., 1979) reductions for HC could range from 14 to 22%, while for CO from 16 to 26%. Accounting for engine deterioration and tampering and assuming the program started in 1979, APCD estimated initial annual reductions of 12% for HC and 14% for CO (13). These estimates appear somewhat optimistic for HC and conservative for CO based on the deterioration data described previously.

A delay until 1980 would increase the expected first year benefits and effectiveness would increase with time as the percentage of 1977 and later model years in the vehicle fleet increases.[2] If the program is begun in 1978 and covers 1974 and later model years, initial benefits are likely to be similar to the benefits obtained in 1980 from a program covering 1977 and later model years.[3]

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[1] EPA estimates that annual benefits for HC are 70% of the initial reduction (6).

[2] A number of other studies for the APCD, based on widely varying vehicle population projections, estimate emission reductions from I/M. One report estimates annual reductions from 1979 to 1985 growing from 6 to 11% for HC and 27 to 51% for CO (14). A more recent study suggests reductions from 1980 to 1985 of 2 to 9% for HC and 6 to 32% for CO (2). EPA Appendix N data suggests that the 1985 emission reductions would be 15% for HC and 20% for CO.

[3] While the initial benefits from I/M are likely to be similar for a program which begins in 1978, the total automobile related pollutants in the 1977-1984 period are likely to be greater due to the relaxation of the federal point of sale regulations.

Cost of Maintenance

The cost of maintenance per vehicle tested and per vehicle failed was calculated as part of the APCD study of 1975 model year vehicles (8) (Table 4-2). The cost data include a $15 diagnostic fee for each failed vehicle but do not include the proposed inspection fee of $5.20. At the 40% rejection rate average maintenance cost per vehicle tested was $7.06 and per vehicle failed, it was $17.66. The average cost for all vehicles failed was $17.50 with costs ranging from $15 (e.g., minor adjustment) to $89. These costs are quite consistent with cost data from several ongoing programs.[1]

At the 40% rejection rate the most frequent repairs or adjustments were for timing, idle mixture or rpm, and the air filter.

Implementation, Administrative, and Operating Costs

From fiscal year 1973 through fiscal year 1977, the total budget for the Mobile Sources Section of the APCD was about $2.4 million. It is estimated by the APCD budget director that at least 60% of this total ($1.45 million) has gone into I/M related activities (including studies of many other vehicle control measures).

While program implementation has since been delayed by a year, cost data developed in 1977 by DOH and DOR give an indication of the additional start up (DOH) and administrative and operating costs (DOH and DOR for the I/M program). Most of the DOR costs are related to enforcement provisions. Table 4-3 presents the cost estimates prepared by the APCD including an estimate of additional revenue needs (15). Table 4-4 presents cost data for

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[1] In New Jersey the average cost at a 12% rejection rate was $32.97, in Oregon with a 35% rejection rate average repair cost was $18.86, and in Arizona with a 47% rejection rate the average repair cost was $25.42 (6).

TABLE 4-2

Maintenance Costs

Rejection Rate	Maintenance Costs ($) Including $15 Diagnostic Fee	
	Per Vehicle	Per Failed Vehicle
10%	2.01	20.12
20%	3.69	18.46
30%	5.32	17.74
40%	7.06	17.66
50%	8.74	17.48
60%	10.55	17.58
70%	12.28	17.54
80%	14.23	17.64
90%	16.31	18.12
100%	17.99	17.99

Source: (8)

TABLE 4-3

Inspection/Maintenance Costs - Department of Health

	1978	1979	1980	1981	1982	1983	1984	1985
Start-Up Costs								
Testing to determine emission standards	$115,000	-	-	-	-	-	-	-
Mechanics training program	$190,000	$190,000	$105,000	$105,000	$105,000	$105,000	$105,000	$105,000
Development of idle inspection procedures	18,400	-	-	-	-	-	-	-
Administrative Costs[1]								
Full-time employees								
Personnel		49,500	52,740	55,600	58,950	62,450	66,242	70,216
Operating		54,000	54,200	54,400	54,600	54,800	55,000	55,200
Travel		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Capital		-	-	-	-	-	-	-
Subtotal		$104,500	$107,670	$111,000	$114,550	$118,250	$122,242	$126,416

[1] Costs include data processing, developing standards for stations and inspectors, developing pass/fail limits, administration of consumer protection, instrument certification, administrative personnel and clerical support.

TABLE 4-3 (continued)

Inspection/Maintenance Costs - Department of Health

	1978	1979	1980	1981	1982	1983	1984	1985
Consumer Protection[2]								
Full-time employees		8	11	14	17	20	23	26
Personnel		$124,000	$170,500	$217,000	$263,500	$310,000	$356,500	$403,000
Operating		20,000	31,000	42,000	53,000	65,000	77,000	90,000
Travel		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Capital		8,000	8,000	8,000	8,000	8,000	8,000	8,000
Subtotal		$153,000	$210,500	$268,000	$325,500	$384,000	$443,500	$502,000
TOTAL COSTS	$223,400	$447,500	$423,440	$484,000	$545,050	$253,669	$268,889	$330,033
Additional Revenue Required								
Full-time employees	0	3	6	9	12	15	18	21
Personnel	0	$45,000	$92,700	$143,262	$196,858	$253,669	$268,889	$330,022
Operating	$218,400	95,000	20,500	31,000	42,000	53,000	64,000	76,000
Travel	0	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Capital	0	8,000	8,000	8,000	8,000	8,000	8,000	8,000
TOTAL	$218,400	$149,000	$122,200	$183,262	$247,858	$315,669	$341,889	$415,022

[2] Costs include the five F.T.E. presently operating the Aurora Testing Station and the mobile testing laboratory, and provide for the establishment and operation of one new Referee Test Station each year to accommodate the growth in the affected motor vehicle population.

Source: (15)

TABLE 4-4

Inspection and Maintenance Costs - Department of Revenue

Category	Year							
	1978	1979	1980	1981	1982	1983	1984	1985
Full-time employees	1.5	12	13	15	16	18	20	22
Inspections		270,366	337,853	490,440	608,850	733,269	863,883	1,100,194
Inspection stations		347	484	628	779		1,106	1,280
Personnel	$23,346	$150,950	$172,165	$207,373	$232,548	$270,775	$313,927	$359,237
Operating	600	22,893	18,160	20,884	24,016	27,618	31,760	36,524
Travel	1,000	2,000	2,800	3,500	4,000	4,600	5,400	6,000
Capital	64,780	12,358	4,000	17,882	4,000	4,000	15,000	12,000
TOTAL	$89,726	$188,381	$197,125	$249,639	$264,564	$306,993	$366,087	$413,761
Estimated Income[1] @.20		$54,732	$75,570	$98,088	$121,770	$146,653	$172,776	$200,038

[1] Assumes program covers 1977 and later model years.

Source: (14)

DOR including an estimate of the revenue likely to be generated by the 20¢ fee for each inspection (14). All figures in Tables 4-3 and 4-4 assume that the program will start in 1980 and cover 1977 and later model years.

An additional operating cost, the cost of performing the inspection, will be borne by the service stations and garages participating in the program. Inspection equipment and necessary facility modifications are estimated to average about $2,300 per station (7). The stations will receive up to $5 to cover these costs and the cost of inspection. An earlier study for the APCD estimated that the labor cost per inspection would be $2.70 (7).

Fuel Economy

The potential fuel economy benefits of I/M are difficult to predict since the repairs and adjustments required for a vehicle to meet emission standards often do not involve a complete vehicle tune-up. In addition, little is known about the fuel economy deterioration characteristics of catalytic converter equipped vehicles. Thus, while it is generally agreed that I/M offers some fuel economy benefits, the estimates of the magnitude of these benefits vary.

The APCD study of 1975 vehicles suggested that fuel economy would be improved by about 1% immediately after repair and was insignificant (8). Another study estimated benefits in the 1 to 4% range which on an annual basis would still only offset the cost of inspection for a failed vehicle (12). If failed vehicles were subjected to a complete tune-up at a 50% rejection rate, a 7.5% increase in fuel economy may be possible (16). Champion estimates that a properly tuned vehicle will average 8.2% better fuel economy over a vehicle which is not kept tuned (17).

SUMMARY OF FINDINGS

1) The only vehicle control measure still under active consideration is an annual inspection and maintenance program. Retrofit and high altitude modification are no longer under active consideration and the potential benefits from both of these measures are decreasing as the vehicle fleet turns over.

2) The major institutional barrier to I/M to date has been legislative opposition. Service industry representatives were opposed to earlier I/M proposals which provided for centralized, state or contractor operated programs. It is proposed that the current program be jointly administered by the DOH and DOR. DOR involvement has increased the acceptability of the program. The legislature is currently considering making the program more stringent and increasing the role of DOR in administering and operating I/M.

3) The I/M program is proposed to begin in 1980, and to cover only 1977 and later model years. However, the legislature is considering new legislation that would start I/M in 1978, and cover 1974 and later model years. The inspections will be decentralized in the private sector. Under the existing bill (SB 231), by July 1, 1979, the legislature must approve the proposed test standards prior to implementation of the program. While the prospects for an I/M program in Denver look better than ever, given the failure of previous I/M proposals due to legislative opposition, final implementation is still not assured.

4) Implementation of I/M began in 1973, when funding for research and studies was made available to the APCD. It now appears that four to seven years will have elapsed before vehicle inspections begin to occur (in 1978 or 1980).

5) Because various I/M proposals became embroiled in and associated with a number of political controversies not directly related to I/M program design, it is difficult to determine to what extent the implementation problems experienced to date could have been avoided. Clearly, a lead time of two to three years appears to be a minimum for the type of program proposed for Denver.

6) The extent to which Denver's specific experience with I/M is transferable will vary markedly. The program was placed in the private sector due to strong opposition to centralized programs on the part of the legislature and the service industries. The fact that the existing safety program is decentralized may have strenghtened the argument for decentralized emission inspections.

7) The estimated administrative and enforcement costs for DOH and DOR will be significant and total more than a million dollars annually by 1985. Less than 20% of these costs are expected to be covered by inspection fees.

8) Even the more conservative estimates of the effectiveness of an I/M program in reducing HC and CO emissions suggest that significant benefits can be obtained (e.g., 10% or greater reductions of both pollutants). I/M will be more effective in reducing CO primarily due to the more rapid post-maintenance deterioration rate for HC.

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CHAPTER 5

EMPLOYER-BASED RIDE SHARING

CARPOOLING VS. RIDE SHARING

A highly visible component of Denver's TCP implementation effort has been their employer-based carpool program. Originally developed by a group of students at George Washington High School in 1973 in response to that year's energy crisis, and subsequently implemented by several Denver employers, the favorable public and private response to this local initiative led the Colorado Air Pollution Control Commission to mandate in Section III of their Regulation 9, adopted July 25, 1974, that all employers having 50 or more employees must provide a carpool locator service and associated employee ride sharing incentives. This was the first instance in the country where a legal basis had been provided by a state to support an employer-based ride sharing program, and Colorado received widespread national publicity for this position of leadership.

This chapter examines the evolution and current status of carpooling in the Denver metropolitan area, examining in particular the implementation efforts of the following organizations:

- Colorado Department of Health, Air Pollution Control Division
- Denver Regional Council of Governments
- Denver Regional Transportation District
- City and County of Denver
- Downtown Denver, Inc.
- Individual private employers
- Colorado Department of Highways

The intent is to place carpooling into a broader context of ridesharing, including options of vanpooling and employer subsidized transit as well as the conventional pre-arranged carpool. While most officials identify DRCOG's carpool matching service as the area's primary (and in most cases, the only) response to the APCC's Regulation No. 9, only about 60 percent of the 343 firms having APCD approved carpool programs as of July, 1976, were utilizing DRCOG's computer services. Important initiatives continue to be taken by the Denver business community and by other parts of Denver government; it is essential that an attempt be made to view the "whole" of what has evolved since 1974 to be a highly fragmented and only loosely coordinated set of public and private ride sharing activities.

It has already been noted that Denver's ride sharing program is more a response to the 1973-1974 gasoline shortages than to the problem of air quality; in many ways, APCC simply adopted an already on-going program to help satisfy the requirements of the EPA promulgated air quality TCP. This kind of opportunism is a widely practiced mode of bureaucratic behavior and frequently is the most effective manner of implementing an innovative and potentially controversial program. It also points out, however, the intimate and supporting relationship between energy, air quality, and transportation objectives when ride sharing strategies are being considered. It is both ineffective and unrealistic to treat the various forms of ride sharing from only a single point of view; rather a multi-objective orientation must be maintained. While Denver, like most U.S. cities, has not performed a comprehensive evaluation of the effectiveness of their various ride sharing activities, interviews combined with an examination of the data that are available indicate the following four central findings:

- Employer-based ride sharing has not yet been implemented in Denver with a coordinated program that is designed to achieve the full effectiveness of ride sharing's potential; in general, ride sharing is considered to be less than a high priority objective.

- The areawide air quality and VMT impacts of the program to date have been minimal, with any modal shift benefits of the program since 1975 being overcome by both increasing real household incomes and a decreasing awareness of a fuel scarcity.

- Still, the estimated savings in annual user or traveller costs of individual programs are far in excess of current agency carpool expenditures. Also, numerous individual employers have initiated both aggressive and innovative ride sharing programs that transcend far beyond the passive approach of providing a carpool matching service and distributing questionnaires. In general, this private initiative has not yet been matched by state, regional, and local government agencies.

- The ride sharing programs to date, both public and private, have resulted in an awareness on the part of many people of commuter travel options other than the drive-alone automobile. Carpooling, vanpooling and transit are not only viewed more positively now than in the past, but also are recognized as available modal alternatives -- even though a decision has not yet been made in most cases to employ a means of travel other than the drive-alone auto. As Denver continues to implement both air quality and energy conservation programs, the already-in-place employer-based ride sharing programs can serve as a highly visible and effective means of demonstrating to individuals that they have the ability to influence both air quality and energy consumption.

THE LEGAL BASIS FOR DENVER RIDE SHARING - APCC REGULATION NO. 9

The Colorado Air Pollution Control Commission took an innovative and bold action when, on July 25, 1974, it adopted Regulation 9 requiring all employers of 50 or more employees within the Metropolitan Denver Air Quality Control Region to provide ride sharing services and incentives. Prior to that time, though, ride sharing had not been considered as an important component of Colorado's air pollution control plans.

The Air Pollution Control Transportation and Land Use Plan prepared by the Air Pollution Control Division and submitted by Governor Love to EPA on May 25, 1973 (1) identifies a "carpool locator service" as one of the alternative measures considered. The service is described as consisting of a region-wide computer data bank of employee data, a matching service, and public information and advertising. The proposed plan, consisting of primary, maintenance, contingency, and secondary actions, however, defines the carpool locator service as only a secondary measure, requiring further study prior to implementation. No separate evaluation of carpooling was performed to assess its potential effectiveness.

The Transportation Control Plan eventually promulgated by EPA on November 7, 1973 (2) continued the low emphasis on carpooling, referring to it only in the requirement for bus/carpool lanes as one of four VMT reduction measures. The carpool locator service as a separate measure is not included, and no particular emphasis is placed on employer-based initiatives.

It was in this context, then, that the Air Pollution Control Commission adopted Regulation 9 on July 25, 1974:

- no previous interest, history or involvement with carpool programs on the part of any state, regional, or local government agency.
- strong private sector initiatives during the 1973-1974 energy crisis with Downtown Denver, Inc. initiating in May 1974 a program to deliver the George Washington High School carpool matching program to 200 major Denver employers.

A copy of Regulation No. 9 is provided as Appendix B. The following, summarizes the key carpool provisions as contained in Section III of the regulation, as amended on November 13, 1975:

- applicable to "all public and private employers which employ more than fifty (50) employees at one time at one site."
- all firms with over 250 employees were to submit plans for approval to APCD by February 1, 1975 and to have the plans fully implemented by April 1, 1975.
- firms with between 50 - 250 employees were to submit plans by August 1, 1975, with full implementation accomplished by October 1, 1975.
- each firm shall implement and maintain a "carpool locator service", with the option of using either the DRCOG computerized carpool-matching program or their in-house service. A carpool is defined as consisting of two or more persons.
- each firm's plan also must include "incentives to encourage the use of carpools and carpooling, bicycle use, and the use of mass transportation services." The incentives, at a minimum, are to include posting of carpool, bicycle, and public transportation information. Other voluntary incentives suggested are free and/or reserved carpool parking, secure bicycle parking and/or storage, on-site sale of bus tickets or reimbursement of fares for the use of public transportation, and adjustments in work schedules.
- employer plans and supporting affidavits are subject to APCD review and approval, with a revision period not to exceed 60 days if disapproved.

- a waiver may be granted if the employer can show cause that the approval criteria are not applicable, are unnecessary because of unique circumstances, or a satisfactory alternative is submitted.
- employers subject to the regulation must submit baseline and annual reports containing the number of employees, modes of travel, and vehicle miles of travel.

The November 13, 1975 amendments added detailed criteria to the basic carpool locator and incentives requirements in order to facilitate both the preparation of employer plans and their approval by APCD. The effort to develop these amendments was initiated in April, 1975, nine months after initial adoption, but in parallel with APCD's implementation efforts and the preparation and submission of employer plans. The approved amendments became effective on January 30, 1976, a period of over two years after EPA promulgation of the Colorado TCP.

In assessing the implementation experience of Regulation 9's ride sharing provisions, it is important to remember that the traditional orientation of air quality agencies has been towards the promulgation and enforcement of quantitative emission standards (lending themselves to the issuance of a "cease and desist order"), to the preparation of plans, or to the performance of studies. In sharp contrast, Section III of Regulation 9 requires employers to initiate a ride sharing information "process" which does not readily lend itself to either quantifiable criteria or the "cease and desist" style of enforcement.

It is within this framework that the response is examined of specific governmental institutions and private employers to APCC's ride sharing legal mandate, and an assessment is made of the accomplishments of the program to date.

THE INSTITUTIONAL RESPONSE TO RIDE SHARING - ASSIGNED AND ASSUMED RESPONSIBILITIES

Because the ride sharing provisions of Regulation 9 encompass public transit and bicycle usage as well as carpooling, several governmental agencies have had important implementation responsibilities. In addition, other provisions of both Regulation 9 and the TCP call for implementation of preferential treatment facilities for high occupancy vehicles. While the experience with these latter facilities is addressed in Chapter 6, it does mean that the attitude and response of the various offices of the City and County of Denver become important determinants of the success of Denver's ride sharing program.

To assist in the assessment of implementation experience, Table 5-1 presents a chronological summary of important ride sharing developments in Denver.

Colorado Department of Health, Air Pollution Control Division (APCD)

Lead responsibility for implementing and enforcing the ride sharing provisions of APCC Regulation 9 is assigned to the 75-employee Air Pollution Control Division of the Colorado Department of Health. This responsibility has been assigned to a single $11,000 per year enforcement officer located within the Division's stationary sources enforcement branch. Except for administrative supervision and clerical support, no additional personnel effort has been directly allocated by APCD to the implementation of Regulation 9 carpooling.[1]

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[1] In comparison, between four and six full-time professionals in the mobile sources section have been involved with the development of APCD's vehicle inspection and maintenance program, and six full-time air quality engineers are assigned to the Division's recently created planning and analysis section with responsibilities for performing air quality analyses, assessing 109(j) consistency, and preparing TCP revisions.

TABLE 5-1

Chronology of Denver Ride Sharing

DATE	AGENCY	ACTION
Fall, 1973	George Washington High School	Development of carpool computer matching program
November, 1973	EPA	Promulgation of Colorado Transportation Control Plan
May, 1974 to September, 1974	Downtown Denver, Inc.	Metro-wide, employer-based ride sharing program; promotion, distribution of George Washington High School computer matching program
July, 1974	APCC	Adoption of Regulation 9
October, 1974	DRCOG	Implementation of computerized carpool matching services
Spring, 1975	APCD, DRCOG, RTD	A series of seven instructional and promotional seminars attended by approximately 300 firms
Spring, 1975	RTD	Initiation of employer-based prepaid ticket and pass program
1975	Individual Employers	Preparation and submission of ride sharing plans
November, 1975	APCC	Amendment of Regulation 9
January, 1975	City and County of Denver	Implementation of Lawrence/Larimer one-way pair, exclusive carpool lanes
1976	Individual Employers	Initiation of private employer vanpooling.
March, 1977	Colorado Energy Policy Council	Submission to FEA of Colorado's State Energy Conservation Plan containing employer-based vanpooling
Spring, 1977	Colorado Department of Highways, Dist. 6	Initiation of vanpooling demonstration program
1976, 1977	APCD	Enforcement of Regulation 9 annual reporting requirements

A total of 788 parent employers are subject to Regulation 9, as tabulated in Table 5-2. Of these employers, 160, or 20 percent, employ over 250 employees; the remainder have between 50 and 250 employees. An examination of the distribution of workers by employer size shows that Regulation 9 affects 59 percent of the total Denver metropolitan area commuting trips.[1] To place Regulation No. 9 into an even broader perspective, work trips account for 37 percent of the region's total estimated daily vehicle miles of travel. The ride sharing provisions of Regulation No. 9, therefore, are directed at a market segment which constitutes 22 percent of total daily travel.

TABLE 5-2

Employers Subject to APCC Regulation 9

Employee Size	Employer Category	Number
≥ 250	Private and State parent employers	135
> 250	Federal agencies	25
50 - 250	Private parent employers	585
50 - 250	City and County facilities	13
50 - 250	Federal agencies	16
50 - 250	School Districts	14
TOTAL:		788

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[1] Firms having 250 or more employees account for 24 percent of Denver area workers, while firms with 50 or more employees include 59 percent of all workers

The employer response, in terms of approved plans, is tabulated in Table 5-3. Of the 424 approvable plans, approximately 300 of these were submitted shortly after the Spring, 1975, seminar series. While the overall percent of approved plans is only 54 percent, the response from employers having more than 250 employees has been excellent and these firms represent 24 percent of total area employment.

APCD, in effect, had the responsibility of taking over a voluntary private sector program and making it mandatory. Their approach has been a combination of education and promotion along with the more traditional enforcement function. Together with DRCOG and RTD, a series of seven seminars were conducted during the spring of 1975 for private employers, with emphasis on direct presentation of material by employers. Approximately 300 firms attended these sessions. These seminars were then followed by separate sessions for public sector employers, and by considerable television, newspaper, and related promotion. During the last two years, APCD emphasis has been divided between enforcing annual reporting requirements and assisting employers on an individual basis. A coordinated effort among APCD, DRCOG, and RTD, such as that which occurred during the seminar series, has not continued.

While our assessment of the APCD ride sharing effort is that it has expanded the benefits of the earlier, privately initiated carpool programs, interviews with a number of people indicate that the results have fallen short of APCC's original aspirations. Several observations can be made in this regard:

TABLE 5-3

Employer Ride Sharing Plans

Employee Size	Employers Subject to Regulation	No. of Plans Received	No. of Plans Approved or Approval Pending	No. of Plans Approved as a % of Total Subject to Regulation
Large (250+) Firms, Private and State Agencies	135	124	112	83%
Large (250+) Federal Agencies	25	25	23	92%
Small Employers 50 - 250	585	260	260	44%
City and County Governments 50 - 250	13	13	13	100%
Federal Agencies 50 - 250	16	11	6	38%
School Districts 50 - 250	14	11	10	71%
TOTAL	788	447	424	54%

Source: (3)

- A staff of essentially one person is not sufficient to work with 788 individual employers, handling promotion, enforcement, and program evaluation. Consequently, the present effort, because of the annual reporting requirement built into Regulation 9, has increasingly become dominated by enforcement. Expansion of the implementation staff by even one or two persons would be highly cost-effective, and would permit resumption of a more balanced overall effort.

- APCD views its primary responsibilities as planning and enforcement. Implementation, particularly where it requires a high dose of promotion and public relations, has not been a natural assignment for a highly technical and engineering oriented agency and consequently "marketing" the ride sharing program simply has not been given the attention that is required to be highly successful.

- Regulation 9, while mandatory, contains no explicit penalty provisions, thereby considerably reducing the leverage of enforcement to gain employer compliance. Combined with the non-quantitative and judgemental "process" orientation of Regulation 9 ride sharing, doubt has been expressed as to whether APCD enforcement actions would be upheld by court review.

- Questions were raised as to the legal authority of the APCC with respect to control of mobile source related pollutants, specifically the Commission's jurisdiction over private employers and related transportation requirements of Regulation 9. These questions were eventually resolved in September, 1976, with a ruling by the Assistant Attorney General that said in part that,"In the field of air pollution control, all individuals, businesses, state agencies, counties, municipalities, political subdivisions and any other legal entity whatsoever which is recognized by law as the subject of rights and duties are subject to the jurisdiction of the Commission. CRS 1973, 25-7-103(12)" (4).

- Finally, the above problems have been exacerbated by an uneven enthusiasm for Regulation 9 within APCD and, as discussed in Chapter 2, the nature of the working relationship between APCD and APCC.

Each employer subject to Regulation 9 rise sharing provisions is required to submit on an annual basis a report to APCD documenting firm size, modal usage, average carpool occupancy, passenger miles per day of travel, vehicle miles per day of travel, and the effectiveness of the particular set of incentives being utilized by the reporting organization. While the majority of the employers having approved plans have now submitted two, and in many cases three, annual reports, APCD has yet to perform any systematic evaluation of these data. The only available APCD evaluation is from July 31, 1975, still in the early stages of the program and prior to the addition of approved criteria to Regulation 9 (5). While it was premature to determine modal shift and VMT reduction data at that time, it is possible to determine some general characteristics of the employer programs.[1]

- Of 111 large firms, 48 or 43 percent were using the DRCOG computer matching services and had developed approximately 10,000 applicants. The remaining 57 percent of the firms had their own locator services, with an employee participation of 19,300. Twelve additional firms were using both DRCOG and their own systems simultaneously.
- Federal and state agencies, proportionally, were much heavier users of the DRCOG services with participation rates of 63 percent and 92 percent respectively.
- The employer incentives reported are tabulated in Table 5-4. The majority of employers even at this early time, had initiated at least minimal incentives to post information, and 28 had gone so far as to provide either free or reserved parking for carpoolers. In addition, several individual employers were providing incentives such as on-site bike parking and bus shelters.

Discussions with APCD employees and others having a responsibility for ride sharing indicated an "impression" that ride sharing in Denver may have declined in the last two years because of the perceived absence of a fuel shortage and the leveling off in fuel prices. An examination of available data to attempt to confirm this hypothesis, however, is fraught with difficulty and frustration. Incentives and disincentives vary from firm to firm, along with a large variation in the degree of enthusiasm for ride sharing. Firms vary greatly in both their geographic and employment characteristics.

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[1] This initial reporting is based on 180 employer organizations and represents roughly 106,000 employees, or 17 percent of the total Denver area work force at that time.

TABLE 5-4

Employer Incentives

Incentive	No. of Employers
Bus Schedules	94
Bicycle Racks	94
Bicycle Maps	28
Free/Reserved Carpool Parking	28
Expand Bus Service	11
Carpool Gift	7
Promote Transit	7
Shuttle Carrier	6
Sell RTD Tickets	6
50% Subsidy for RTD Usage	5
Adjust Work Schedules for Carpool	5
Carpool Parking Subsidy	4
In-Building Bicycle Parking	3

Source: (5)

Most firms are either growing or declining in size, making yearly comparisons difficult. Finally, both the methods and quality of data collection vary among firms, introducing a source of error.

Still, some kind of evaluation is necessary to assess the program's success. One such study was performed by the Institute of Behavioral Science at the University of Colorado (6). A survey of nine firms, each employing more than 250 persons, was made to determine changes in carpooling and transit from May, 1975 to May, 1976, with the objective of relating the amount of change to the type of incentive program utilized. Their conclusion is that current plans "have been far from successful." Of the nine firms examined, two were judged as good, two as mixed, two as mediocre, and three as bad. Changes were examined to determine the switch from drive-alone to either transit or carpooling; no attempt was made to separate these "alternate" modes.

Our own examination of data from a sample of twelve firms indicates equally "mixed" results, although carpooling increased by an average of 3.8 percent per firm. The range, however, was great with the relative change varying from a decline of 53 percent (in a firm which doubled in size) to increases of 43, 66, and 78 percent. Eight of the firms reported lower carpool mode shares in 1977 than in 1975, while four reported increases. The firm that increased carpooling from 5.0 to 8.9 percent also increased transit utilization by 17 percent as a result of its agressive ride sharing promotion efforts. If all firms are considered together, the number of carpoolers increased from 863 to 918 while employment grew from 4432 to 5183. This results, though, in a two-year decrease in carpooling mode share from 19.5 to 17.7 percent. However, if the one firm is eliminated which grew from 562 to 1087 employees during this period, carpooling increased in percentage as well as absolute terms; 18.6 to 19.2 percent or from 718 to 786 carpoolers. Considering a somewhat larger sample of 16 firms, 6 (38 percent) utilized their own matching systems, 9 (56 percent) used the services of DRCOG, and 1 (6 percent) used a combination of both.

Denver Regional Council of Governments (DRCOG)

The Denver Regional Council of Governments is assigned responsibility by APCC Regulation 9(7) for providing a carpool locator service for use by Denver employers. The program was initially assigned, in January, 1975, to DRCOG's Director of Public Affairs, a former Denver city official who had good contacts with many of the large Denver employers. With this person's retirement in early 1977, the program has been relocated to the Council's Membership Services Division (Figure 2-2). DRCOG's Transportation office has had no formal role in implementing the carpool program, although they have worked on a periodic basis with the Carpool Office.

Federal Highway Administration Urban System's Funding has been used to support the program with the 10 percent local match coming directly from the approximately $420,000 which is raised annually by DRCOG through local community membership dues. The apportionment is divided approximately equally between the City and County of Denver and the surrounding towns. An initial funding of $181,500 was used to cover start-up costs and it is anticipated by DRCOG that the service will be maintained at approximately the $100,000 per year level as seen in Table 5-5. This funding supports the following program:

- one full-time professional staff member
- one half-time clerk/secretary
- data processing staff
- computer time
- expenses for promotional material

Thus, while DRCOG has considerably higher ancillary expenses than does APCD, the programs from an employer perspective are essentially equivalent in that each is staffed by one full-time person. The DRCOG professional, though, is classified as a "middle-level person" and is paid in the range of $15,000-18,000 per year in contrast to APCD's $11,000 per year.

TABLE 5-5

Carpool Program Expenditures by Urban Area

City	Expenditures	Reported Annual Benefits/Costs[1]
Denver	$181,500 (1975) 107,000 (1976) 97,000 (1977)	1.7 3.0
Sacramento	$172,970 (30 months)	14.3
Los Angeles	$800,000 (1976 est.) 948,660 (1976 budget)	
Boston	$643,000 (1976 - 1977)	
Boise	$ 64,786 (1975 budget) 40,922 (1975 expenses)	5.9
Fort Worth	$ 80,000 (1976 budget) 68,821 (1976 expenses)	9.4
Dallas	$166,014 (1976 expenses)	
Houston	$ 81,848 (10 months, 1975 expenses)	23.0
New Orleans	$215,000 (1974 budget)	
Providence	$175,000 (34 months)	7.8
Portland	$ 81,084 (1975 budget) 214,200 (1974 expenditures)	57.0

Source: (10,9)

[1] Benefits are not estimated on a consistent basis from city to city

Compared to other federally funded carpool programs (Table 5-5), DRCOG can be described as being "about in the middle" with respect to expenditures (and,as will be shown, with respect to effectiveness as well).

DRCOG's carpool program is oriented around three basic activities:

- Maintenance of a computerized carpool matching program based on use of the U.S. Census Bureau's DIME (Dual Independent Map Encoding) file and UNIMATCH program (8). Five hundred twenty-five square miles of Denver are represented with a one-mile grid system and social security number represented applicants are matched by origin and destination grid within a ± 15 minute period of their arrival and departure time. The program is run at United Air Lines Denver reservation center using an IBM 360/195 and a matching rate in the 80-90 percent range is being achieved for the first shift employees. Consideration is being given to the addition of transit information, in addition to carpool match lists, to the current program.
- Assistance to employers by providing promotional material in the form of "Double Up" booklets, "14 Tips" on carpooling, form letters, applications, savings estimates, example outputs, and similar types of support material.
- Mass media promotion through newspaper advertisements, public service television announcements, and use of the Colorado Department of Highway's variable message freeway signs.

While DRCOG was a participant in the 1975 carpool seminar series, no direct program of employer visits or active employer promotion is being maintained. Rather, the position of DRCOG is that the carpool matching program is "made available" as a service to interested persons and employers nad that the DRCOG staff person is available on a "consultative" basis if requested. A recent DRCOG analysis (9) indicates that 210 firms or organizations, with each having 10 or more employees as applicants, were using the matching system. The 210 employers corresponds to 61 percent of APCD's 343 approved employer plans and 47 percent of their 447 submitted plans (as of July 26, 1976).

The carpool locator service represents the first transportation action for which DRCOG has assumed a direct implementation (as opposed to planning) responsibility. While the benefits of this action for a COG cannot be overstated, there have nevertheless been a number of problems which have been encountered:

- DRCOG has not wished to be closely associated with a state (APCD) program which imposes requirements on local communities or employers and for which enforcement actions could be initiated; they much prefer the voluntary approach.

- Similarly, DRCOG has not felt it was appropriate, given the voluntary and community basis of their organization, for them to aggressively promote carpooling to anywhere near the degree that other efforts have shown is necessary in order to be successful.

- Information on many of the system's 21,636 applicants became erroneous as a result of employee terminations, residential moves, a carpool already being formed, or other changes in status. This resulted in incorrect "matches" being distributed by DRCOG, and a resulting credibility problem with both employers and applicants. Recently distributed "purge" questionnaires to all 21,636 applicants had the following results:

- returned	9,314	42%
- not returned	11,932	56%
- wrong address	403	2%

  Of the 9,314 returned:

- request to delete	6,506	70%
- desire to be active	2,808	30%

  Of the 11,932 not returned, a follow-up employer telephone survey indicates that 7,392 should be retained in the active file.

- Employers have complained of delays between the submission of employee applications and the return of a match list. While these delays are no doubt related to DRCOG's concern over the distribution of inaccurate information, they have contributed further to the "credibility" of DRCOG as an implementing agency.

The effectiveness of APCD's carpool program was characterized as "mixed"; much the same assessment can be made of DRCOG's carpool program, although DRCOG has performed evaluation analyses both at the end of 1975 and 1976. The program grew from 15,262 to 21,636 applicants during this period (implying a cost of $16.80 per applicant). The DRCOG effectiveness calculations are summarized in Table 5-6, showing a comparison to the 1975 results as well. The figures for 1976 demonstrate a positive benefit cost ratio of 3 to 1 based on 2,936 carpoolers, 1,165 carpools formed, 1,164 vehicles eliminated, 7,624,200 miles saved annually, 544,585 gallons of fuel saved annually, and $321,304 saved annually in fuel costs. They translate into a user fuel cost savings of $276 per year per new carpooler, and an average program cost per carpooler of $131. The dollar benefits could be increased if it is assumed that the approximately 40 percent of APCD employers not using DRCOG's services are achieving the same effectiveness rate. While the DRCOG figures are low when compared to the figures of other programs, Table 5-5, it is known that all figures are not calculated on an equivalent basis. For example, using published FHWA data and assuming costs of oil, maintenance, parking, insurance, and depreciation, these same statistics would translate into a user savings of approximately $750 per year (assuming a compact car) compared to driving alone.

A telephone survey of a 491 person sample in November, 1975, by the Colorado Communications and Campaign Consultants (11) produced similar benefit analyses. The survey, however, also produced a number of other findings, some of which raise serious questions about the effectiveness of the carpool program:

TABLE 5-6

DRCOG Carpool Program Benefits Estimate

Calculations

Based upon the responses of 2,808 applicants who wanted to remain in the active file, the following data was gleamed:

Survey showed the following:

1. Occupants per carpool	2.52
2. Average carpool days weekly	4.98
3. Daily average round-trip mileage	26.23

2,536 of the applicants were actively participating in a carpooling arrangement, the remaining 272 applicants requested new pooling print-outs to assist them in establishing new carpools.

The 400 individuals who requested deletion because of full carpools could be assumed to be more impressive than the above data; however, because of those individuals didn't complete the statistical section of the questionnaire, further extrapolation of this data is not possible at this time. Therefore, 400 individuals will simply be added to the total number of applicants actively participating in ride-sharing opportunities.

Based on these averages, the following calculations are reached:

	Current	75 Data
Carpools formed (2,936 ÷2.52)	1,165	1,320
Carpools trips weekly (1,165 x 4.98)	5,698	5,953
Carpools trips annually (5,698 x 50 weeks)	284,900	297,650
Carpool miles per year (284,900 x 26.2)	7,464,380	6,488,770
Total mileage for all poolers (7,464,380 x 2.52)	18,800,237	17,714,342

Assuming 40% of poolers were drivers only prior to program:

	Current	75 Data
Number of cars removed from the streets	1,164	1,442
Trips saved weekly (1,164 x 5 days)	5,820	7,210
Trips saved annually (5,820 x 50 weeks)	291,000	360,500
Miles saved annually (291,000 x 26.2 miles)	7,624,200	7,859,000
Gallons of gas saved @ 14 mpg	544,585	561,350
Barrels of oil saved @ 42 Gals. per barrel	12,966	13,365
Money saved @ 59¢ per gallon	$321,304	$308,743
Saving per new pooler	$ 276	214.10

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	Current	75 Data
Carbon Monoxide	849.34	875.49
Hydrocarbons	56.42	58.16
Oxides of Nitrogen	20.20	20.83
Sulfer Oxides	1.10	1.14
Particulates	2.86	2.95

Source (9)

- 23.6 percent considered themselves as participants in the program
- 59.7 percent have either dropped out or never started carpooling
- 37.1 percent of the employers offer special incentives, with preferred parking being provided in 67.5 percent of these cases
- 19.8 percent of the carpoolers cite the DRCOG program as the reason they started carpooling
- 61.2 percent were carpooling prior to the start of the DRCOG program
- 96.6 percent want to continue carpooling

The recent DRCOG "purge" analysis, both confirmed and contradicted the earlier survey (9):

- 85 percent of the respondents reported that their employers provided no incentives to ride sharing (presumably meaning incentives in addition to posting of information)
- 85 percent of the respondents, however, first learned of the DRCOG carpool locator service through their employer (with 10 percent via media promotion and 5 percent by other means).

Denver Regional Transportation District (RTD)

The third major participant in implementing the ride sharing provisions of Regulation No. 9 has been the RTD, with particular responsibilities for assisting employers in promoting transit. As shown in Table 5-7, 81 percent of Denver employees are served by transit, although transit in-vehicle travel time is nearly double that of the private auto for all segments of the population.

While major RTD attention has been devoted to the PRT and LRT rail transit proposals and currently to the 16th-Street mall, their marketing department has worked during recent years with over twenty employers to discuss ways of providing new or better bus service. In addition, RTD has instituted a system of prepaid tickets and passes which can be purchased at various locations in Denver and has encouraged employers to subsidize transit usage. Table 5-8 identifies, as of September, 1975, six different

TABLE 5-7

Transit Availability For Denver Work Trips

Market Segment	% With Transit Available	Average In-Vehicle Travel Time (mins.)[1]	
		Auto	Transit
Income			
Low	87	27	52
Mid	82	34	61
High	79	35	67
Residence Zone			
Urban	91	29	46
Suburban	82	34	67
Exurban	67	39	76
Auto Ownership			
0	83	-	29
1	84	32	63
2	69	35	65
TOTAL	81	34	63

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[1] round trip

Source: (12) 1975 Level of Service Network

TABLE 5-8

List of Firms Employing Selected Transit Incentives

On-Site Sale of Bus Tickets

CTI - Nuclear, Inc.
(may sell at a later date)

Dravo Corporation

Hamilton Management Corp.

Mountain States Bankcard Assoc.

National City Bank of Denver

Lakeside National Bank

Bus Subsidization

Baldwin Deco Service Center

Cahners Publishing Co, Inc.

Colorado National Bank

Denver Automotive and Diesel College, Inc.

Education Commission of the States

Miller International Inc. (periodic)

Security National Bank

Transit Management Co., Inc.

Petro Lewis Corp. (periodic)

Flexible Hours

Aetna Insurance Co.

CNA Insurance Co.

Dun and Bradstreet, Inc.

Hilb and Co., Inc.

Perfection Tip Co.

Western Farm Bureau Insurance

Periodic Gift Drawings

Dravo Corp.

Miller International Inc.

Scientific Software Corp.

Kaiser Foundation Health Plan of Colorado

Have Negotiated or Plan to Negotiate with RTD for New Services

City of Aurora

City of Thornton

Burkhardt Steel Co.

Chemetron

Elba Systems Corp.

Monaghan Plastics

Montgomery Wards (for express service to Montbello office)

Eversman Manufacturing Co.

Desire New Service

Boise Cascade

Denver Brick and Pipe (polled employees to survey interest)

Lear Siegler, Inc./Environmental Technology Division (reports that they would encourage transit if available)

Midwest Steel and Iron Works Co. (#25 Larimer St.) (reports that they would encourage transit if available)

Ragsdale Bros., Inc. (reports that they would encourage transit if available)

Barber's Poultry, Inc. (reports that they would encourage transit if available)

Source: RTD, September, 1975

transit promotional efforts in use by various firms, with nine employers involved in some form of bus subsidization at approximately the 50 percent level. Of these, United Banks of Colorado started the program in 1972 and has increased employee transit utilization from 24.9 percent to 54.4 percent; Colorado National Bank also started their program in 1972,with an increase in transit modal share from 22 to 38 percent; Central Bank of Denver, starting in April, 1975, has increased transit ridership from 15 to 28 percent. The recently (August, 1976) initiated downtown Free Ride circulator bus,initiated in August, 1976, should reinforce these efforts, resulting in increased commuter use of transit as well.

While the above figures are impressive, four of the employer subsidy plans were already in place by 1974, prior to implementation of Regulation 9, and the program did not expand significantly during 1976 and early 1977. Only loose coordination has been maintained with APCD since the initial seminar series. In contrast to the Boston MBTA employer pre-paid pass program which had arranged with 370 employers as of May, 1977 to sell monthly transit passes through a payroll deduction plan, RTD markets their passes only at ticket centers rather than working directly with employers. RTD, however, has been a leader in gaining support for employer-subsidized transit (to correspond with employer-subsidized parking), with nine firms providing this equity benefit in contrast to Boston's four.

City and County of Denver

The Denver City Council was one of three area councils to approve, in 1974, upon the urging of Downtown Denver, Inc., a resolution in support of carpooling as a means of supplementing the city's transit system (13).

Since that time, though, the City and County of Denver has not taken an active role in either promoting carpooling or assisting in the implementation of the employer-based ride sharing provisions of APCC Regulation 9. In fact, the position of the City administration, as discussed in Chapter 2, has been not to take any action which could be construed as a limitation on the use of the private automobile. This position with respect to carpooling was most evident by their lack of support of the Lawrence-Larimer carpool lane demonstration project.

A possible change in this position could occur as a result of events initiated in 1977 between the APCD and the City, for the City's Department of Health and Hospitals to assume more direct involvement in the enforcement of the Regulation 9 ride sharing provisions for all firms located within the City and County of Denver. Such a shift is being encouraged by APCD staff and also was endorsed by the Colorado Assistant Attorney General's statement that the Air Pollution Control Acts (CRS 1973, 25-7-125) "allows the Commission to adopt an overall control program with the flexibility of allowing local units of government to adopt, submit and, upon review by the Commission for compatibility and effectiveness, implement measures which are designed and administered for the local situation by the responsible local officials." (4)

Private Employers, Downtown Denver, Inc. (DDI)

The Denver ride sharing program grew out of employer-initiated actions and continues to enjoy widespread -- though far from unanimous -- employer support. Twelve firms implemented the George Washington High School computer matching program prior to the start of Downtown Denver, Inc.'s promotional campaign in May, 1974. With initiation of the DDI Carpool Office, the number of Denver firms with carpool programs increased to 22 (14). An additional 57 firms had committed themselves to a carpool program, and 38 reported a positive attitude towards carpooling but that either a decision was still pending or that they were undecided. Of the 202 firms with which DDI was working, 106, or 52.5 percent, had a negative response towards the initiation of an employer-based ride sharing program. (This figure is remarkably similar to the 56.5 percent of the 788 employers subject to Regulation 9 that still had not received APCD Certificates of Approval as of July 26, 1976.)

DDI's carpool program was strongly promotional and personalized in character and was aimed at gaining support for the program for both management and the individual employee (15). The program was built around three features:

- Dissemination of educational materials to the public and media. This included the development of newspaper features, stories, monthly press releases, public service radio announcements, a monthly newsletter, and the holding of promotional events. These latter "Pool-It Parties" were held at CBD shopping areas and public parks in cooperation with retail businesses and included live entertainment and carpool artwork developed by junior high school students.

- Dissemination of promotional materials within businesses. Direct communications were maintained with 202 firms via individual briefings, the use of promotional material such as "The Care and Feeding of a Carpool," developed in part by the Rocky Mountain AAA, and the distribution of the monthly newsletter, "Carpool News."

- Coordination of local agency support. Local governments and agencies were encouraged to take an active role in the carpool program through formation of an Advisory Committee, presentations at executive club meetings, and the securing of endorsements by area city councils via resolutions passed in support of carpooling.

APCD staff estimated in 1977 that approximately 35 firms were "aggressively" promoting carpooling in the Denver area. While many of these employers have made a strong effort to promote ride sharing on their own initiative, they also have responded in part to the efforts of DRCOG and APCD as well as of DDI. The Great Western Sugar Company and the Air Force Accounting and Finance Center were explicitly commended in the 1974 Denver City Council resolution. Other employers which have been cited, to name only a few and to omit many, include Public Service Company, United Banks of Denver, Chevron Oil, American National Bank, Central Bank and Trust, Brown Palace Hotel, Mountain Bell Telephone, Trans-America Title Company, Insurance Companies of North America, and the National Bureau of Standards. At least three Denver employers are known to have initiated vanpool programs: CONOCO, Statitrol, and Johns-Manville.[1]

The DDI promotional effort was downtown oriented, as are many of the firms named above. Suburban firms, however, also have been responsive, with the Denver Technological Center serving as an excellent example. DTC is a totally planned new business community located on 850 acres of land (twice the size of the downtown Denver business district), approximately 18 miles southeast of the CBD. It consisted, in 1977, of 125 individual companies with about 3100 total employees. Only ten of these firms have more than 100 employees, with the largest being Diners Club (700 employees), United Airlines (330), United Banks (220), and Honeywell(200). Among the major features and benefits of DTC, as cited in their promotional material, are a carpool system and public transportation services. Starting in

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[1] These vanpool programs are described in more detail in the next section.

March, 1975, and working with DRCOG's matching program, a carpool committee was established under the leadership of Diner's Club, United Airlines, and the DTC developer itself. Descriptive and promotional material, including matching questionaires, are given to each new tenant, and a carpool submission is made routinely to DRCOG on the first of each month. Both Diner's Club and United Airlines reported an initial increase in carpooling (United Airlines, from roughly 10 to 15 percent of their day workers) although no additional incentives are employed. Both firms acknowledge, though, that their respective carpooling modal shares may have declined in the last year due to the lack of DRCOG responsiveness, staff reductions, employee turnover, and "general complacency", although continually shifting employment and data collection problems make precise figures difficult to determine. DTC also reports that,while carpool matching is pooled through the use of the DRCOG matching services, the large majority of individual carpools still draw their members from within single firms.

Vanpooling

In many areas of the country, vanpooling has constituted a logical extension of employer-based ride sharing programs, with probably well over 85 companies having introduced such programs since the 3-M Company's pioneering vanpool efforts in 1973. Over 2000 employer-based vanpools are estimated by the Department of Energy to be in operation now on a national basis (23). While vanpooling has been most frequently organized at the individual employer level, and typically in firms with 500 or more employees, leased, individually purchased, brokerage, and multi-employer concepts also have proven successful.[1]

Vanpooling is priced to be self-supporting and normally becomes economical from the commuter's perspective when one-way trip distances exceed a minimum in the range of 10 to 15 miles (22). Monthly costs per rider are typically in the range of $20 - $30 or approximately $0.06 per mile. Vanpool modal shares in the order of 10 percent within individual firms are not uncommon (16,17,23).

In Denver, vanpool programs have been established by at least three employers -- Statitrol, CONOCO, and Johns-Manville -- and the District 6 office of the Colorado Department of Highways in conjunction with DRCOG is implementing an employer-based vanpool demonstration program.[2]

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[1] Much of this interest in vanpooling is the direct result of strong federal leadership, combined with the activities of the National Association of Vanpool Operators. The Federal Energy Administration, now the Department of Energy, has conducted an extensive series of vanpool workshops. The Urban Mass Transportation Administration currently is supporting four vanpool projects under its Service and Methods Demonstration Program. The Federal Aid Highway act of 1974 contained a vanpool abort provision that guaranteed recovery of any financial losses for a vanpool that did not prove to be successful. This was extended in the Federal-Aid Highway Act of 1976 that authorized federal highway funds to be used as a no-interest loan to cover 90 percent of the initial van purchase price and other personnel and direct costs of a vanpool program.

[2] In addition, RTD initiated, during the Spring of 1977, a vanpool-type service in Nederland, a small rural community near Boulder that previously had no public transportation services. Leased to an individual who also served as the sole operator, the van operated on a subscription basis during the weekday peak (with a monthly fare of $30.80 for a 25-mile daily round trip) and provided a demand-responsive service to the elderly and handicapped during the off-peak. In the September 1, 1977, agreement between RTD and the Amalgamated Transit Union, it was agreed that drivers for such irregular service in rural areas would be paid at a rate equal to 50 percent of the top operators rate. or $3.60/hour. As a second RTD vanpool effort, a program was initiated during the Spring of 1978, in cooperation with the Department of Energy, where RTD would lease 10 vans to Rockwell International.

Statitrol, an electronics manufacturing corporation located in Lakewood, is a firm which has aggressively promoted carpooling and vanpooling, with corresponding levels of success. With a total employment of 650 and two plants (with 325 and 225 employees respectively), the current carpool modal share is approximately 45 percent. Each location has had one 12-passenger van, in operation since 1976 serving hourly employees, with plans to obtain two additional vans. The expanded van service may be made available to salaried personnel as well.

Van fares are on a trip mileage basis and are collected via payroll deduction. Each van is operated by a Statitrol employee who then has the van available for personal use during evenings and on weekends. During the day, the vans are used for an inter-plant shuttle service, transporting both employees and packages. As an incentive to the vanpool driver, the driver pays no fare and the break-even fare is set at eight passengers, so the fares from the ninth, tenth, and eleventh passengers represent direct reimbursement to the driver. Further, Statitrol provides a low-level subsidy for each van as an additional employee incentive. Van parking is immediately adjacent to the door, with preferential carpool parking immediately following.

The Statitrol ride sharing program enjoys strong, top-management support, with a primary motivation for the promotion of ride sharing being a lack of parking; spaces are available for less than half the number of employees. The program is administered by their personnel department with a minimum of effort. Van insurance is covered under their corporate liability coverage. Statitrol has chosen not to use DRCOG's carpool matching service, feeling the computerization adds unnecessary paperwork and delay and that such a system is not sufficiently responsive to either new or recently moved employees. Instead, they maintain a matching map with numbered pin flags.

Employee response to the ride sharing promotion is reported as excellent with comments such as "exciting" and "better than the bus." During the peak energy crisis, a number of incentives were employed in addition to preferential parking. These included monthly free lunches for carpoolers, raffles, and the giving away of silver dollars. In this peak promotional period, carpooling averaged 55 percent. These promotions, however, have not continued and, in combination with a major growth in the number of employees, the recent carpool modal share has declined to around 45 percent.

CONOCO's Denver operations are headquartered in the downtown area, and their 200 employees consequently are well served by transit. Still, as a spinoff of their Houston vanpool program, they have established two vans to serve residential areas that are located 15-25 miles away, obtaining a vanpool modal share of 12 percent in a firm that is normally considered too small for vanpooling.

Johns-Manville's vanpool program, in contrast to the above two efforts, has been less successful. While the recently relocated 1,900 employee corporate headquarters is located approximately 40 miles southwest of Denver and is not near residential areas, vanpooling does not have strong top management support and it is company policy that all vans be completely self-supporting. Further, plentiful free parking is available and many of their employees travel extensively. Of an original three leased vans, one was replaced by new RTD service, one was discontinued because it was operating at a loss, and one is at full capacity serving a 40-mile one-way commute.

The Colorado Department of Highways (CDH) is the newest government participant in Denver's ride sharing effort with the initiation of the District 6 vanpool demonstration program. While the Department has supported carpooling in the past -- for example, by using their freeway variable message electronic controlled signs to advertise DRCOG's carpool matching telephone number -- this is their first active participation involving personnel in a promotional effort. Working in cooperation with DRCOG, the demonstration is being undertaken as part of the effort to implement Colorado's State Energy Conservation Program and is based on $132,000 of Federal-Aid Highway funding. As of early 1978, ten vans were being placed in service with plans to extend this to 35-40. One problem which has delayed implementation has been the difficulty of developing the necessary contracts between the employer and both DRCOG and CDH. Another key question is the duration of time for such a demonstration or pilot program, especially in light of FHWA's apparent policy that carpool/vanpool related continuation funding must be based on new efforts as opposed to maintenance of already established and on-going services.

Two barriers to vanpool implementation on a national scale have been the precise manner in which vanpools, as essentially a new mode of transportation combining many of the positive features of transit and carpooling, would be insured and regulated. To date, however, these have not constituted significant problems in Colorado. The vans have been treated as an addition to the corporation's vehicle fleet, with insurance coverage provided as part of the standard fleet policy, and employee injuries covered by workmen's compensation rather than by the vehicle liability policy.[1]

The Colorado Public Utilities Commission classified Statitrol Corporation's vanpools as a common carrier, thereby subjecting them to increased regulation, higher insurance, and additional taxes; though both the Johns-Manville and CONOCO vanpool programs remain unregulated (19,20). Under Colorado Revised Statutes, the latter interpretation would seem to be the more correct, since the existing Colorado vanpools are not "used in serving the public" (CRS 40-10-101(4)) which is required by the statutory definition of a "motor vehicle carrier" (common carrier). Further, a contract carrier is defined as "every corporation, person, firm, association of persons... other than motor vehicle carriers... in the business of transporting persons ...for compensation or hire," (CRS 40-11-101(3)). Since employer vanpools do not constitute a business and, further, are considered a non-profit arrangement (confirmed by the Insurance Services Office (18)), regulation as contract carriers also would seem to be inappropriate.

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[1] Vanpool insurance problems, in general, have been considerably eased by the April 4, 1977, filing of the Insurance Services Office which defines employer furnished vanpools, for the purposes of insurance, as being in the lowest rated commercial auto classification (18). Rating factors vary by vehicle occupancy and can be used to cover station wagons, vans, or buses used in a pooling situation where the "transportation is held out by the employer as an inducement to employment, or condition of employment or is incident to employment." Further, it is assumed that the vanpool operates on a non-profit basis, that the costs "are paid for by the employees utilizing such arrangements," and that the employees are covered by workmen's compensation.

SUMMARY OF COMMUTER, EMPLOYER, AND AREAWIDE IMPACTS

Previous sections of this chapter have examined the response of specific governmental agencies and individual employers to ride sharing. While several examples of successful individual efforts have been demonstrated, it also has been clear that there has been resistance to the widespread implementation of ride sharing. This section summarizes ride sharing benefits and costs from the perspective of both the commuter and the employer, and then examines the areawide potential of various employer-based ride sharing strategies to contribute to both air quality and fuel conservation improvements.

From the commuter's point of view, ride sharing can offer the potential of significant economic benefits, but unfortunately also can impose certain non-economic costs. The specific tradeoffs, however, will vary with each individual depending upon his or her particular set of values. As discussed previously, Table 5-6, DRCOG has estimated an annual savings of $276 for fuel costs alone (9). Including both other vehicle operating costs and an allowance for parking charges increases this to $750 per year per carpooler.[1] Further, if it is possible to reduce a household's automobile ownership by one car due to ride sharing, this could result in an additional annual $1000 savings in auto ownership costs (depreciation, insurance, taxes).

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[1] Other savings estimates may be somewhat more conservative. For example, a potential annual savings of $576 is derived based on marginal vehicle operating costs of $.07 per mile for a compact car, a 15-mile one-way commute, a 3-person carpool, and a daily parking charge of $1.50. If parking is free, as typically would be in the case in the suburbs, the annual savings are reduced to $336.

The costs to achieve these dollar benefits are generally non-economic:

- approximately a 10 percent increase in travel time due to the circuity of picking up and dropping off passengers. (This can be offset through the provision of preferential carpool parking, or through the use of preferential ramp and lane treatment for carpools).
- a loss in flexibility in departure time and the ability to use the car during midday for either business or personal purposes. A carpool can be characterized as being equivalent to a transit frequency of one trip per peak period, though in most cases it is one which can be conveniently scheduled.
- possible increased psychological stress resulting from a loss of "alone" time, the lack of a quiet transition between a person's work and home life, or a feeling of being compelled to be friendly and make conversation with the same people at the same time each day. Various forms of economic, social, and racial structure existing in our society may make it difficult for some people to carpool together. The traditional American status symbol of the personally owned automobile or the "two-car" family has resulted in a certain degree of prestige to driving alone to work.

Uncertainty over insurance coverage was an issue to both commuters and insurance companies during 1973 and 1974. These concerns, along with the closely related issue of carpool/vanpool safety largely have been overcome today. In Colorado, the Commissioner of Insurance issued a notice on January 2, 1974, to all Colorado automobile insurance companies stating that it would be in violation of the "Uniform Claim Settlement Practices" (CRS 72-14-4(1)(1)) if a company invokes the "car livery and public conveyance exclusion" with respect to an accident involving either a "share the expense" or a "share the driving" carpool. Further, the Commissioner expressed his opinion that employers would not be liable for merely encouraging carpools and providing certain incentives.

A vanpool survey by the then Federal Energy Administration, now the Department of Energy, confirms that insurance issues likely will continue to diminish (21). Vanpools have accumulated an accident rate of 3.76 accidents per one million vehicle miles, based on 158,436,286 passenger miles of reported travel. This compares to 6.36 for passenger cars and taxis, 26.3 for suburban buses, and 57.3 for urban buses.

The benefits and costs to an employer, as with the individual commuter, will vary considerably with the unique context of each firm. The Downtown Denver, Inc., survey of firms, together with our own interviews, found basically the standard reasons for supporting and opposing employer-based ride sharing (14). Reasons for a firm being committed to the program include the following:

- Strong management endorsement and support
- Sense of civic responsibility
- Desire to solve a parking problem
- Desire to assist employees in finding an economical means of transportation between home and work, and therefore increasing employee morale
- Means of reducing employee tardiness and absenteeism
- Desire to decrease congestion at entrance and exit roadway facilities

With typical monthly per space parking costs to an employer of $15 for outdoor facilities and $30 for garages, the ability to eliminate construction of new parking to accommodate corporate expansion frequently is sufficient incentive for an agressively promoted ride sharing program. This is especially the case given the finding, based on our interviews, that the administration of a ride sharing program requires relatively little effort by an employer. In most cases, it is simply handled as an additional task by the personnel department with no staff changes required and only a minimal amount of direct expenses.

Reasons cited by firms which have either not implemented a carpool program or which are complying only with the letter, but not the spirit, of Regulation 9, include the following:

- Lack of management endorsement and support
- No perceived need for carpooling
- No interest among employees
- Low density of employee residential locations
- Shift differentiation or lack of regular hours
- Need for cars during business
- Number of employees too small
- Cost to firm of providing the service
- Want to treat all employees equally
- Do not wish to expand employee benefits
- Do not want to raise a potential issue for future labor negotiations
- Employee layoffs are being made, and it would be inappropriate to simultaneously offer additional services
- We are just too busy with other programs.

Of the 202 firms surveyed by DDI, the lack of management interest was the single largest reason cited (27.1 percent of the cases) for a firm's non-commitment to carpooling. Conversely, in firms where carpooling was found to be successful, it enjoyed the strong endorsement of top management and tangible incentives, such as preferential parking, had been implemented to encourage ride sharing.

The implementation of a vanpool program, or a subsidized transit pass program clearly involves a larger commitment on the part of an employer than does simple carpool matching and promotion. Vans cost approximately $7,000 to purchase and employers generally have absorbed this front-end expense directly, along with other one-time or annual costs such as insurance. While these costs normally are recovered, it does involve an element of risk, an additional outward cash flow, and a possible opportunity cost in that these funds cannot be used in another way that might be more directly profitable to the firm.[1] The Federal-Aid Highway vanpool provisions are specifically designed to overcome these problems.

While it is clear that ride sharing can in many cases provide significant benefits to both the employer and the commuter, the important question from an air quality and energy perspective is how many employers and individuals on an areawide basis will choose to take advantage of these benefits. Stated another way, given that 19 percent of Denver workers already are ride sharing for the trip between home and work, is the market segment for which ride sharing might be superior to either driving alone or transit, and which is not already ride sharing, sufficiently large so as to be able to achieve meaningful areawide benefits? To answer this question, eight separate combinations of employer-based ride sharing strategies were examined using a 1975 analysis year and the set of household level disaggregate travel demand models summarized in Appendix C. The results of these analyses are provided as Table 5-9 and summarized in Figure 5-1. An analysis of the changes in transportation behavior leads to the following conclusions:

1) Full employer compliance with the ride sharing provisions of APCC Regulation No. 9, as simulated by Policy 2, would lead to a 13 percent increase in ride sharing and a 1.4 percent decrease in work trip vehicle miles of travel. An employer size limit of 50 or more employees (Policy 2) achieves approximately twice the impact of a 250 employee size limitation (Policy 1).

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[1] This one-time outlay of funds is not unlike, and may be considerably less than that required to construct new parking facilities, however.

TABLE 5-9

VMT Reduction Potential of Employer-Based Ride Sharing

% Change from Base, Areawide

	WORK TRIP MODE SPLIT				Work Trip VMT (Miles/Day)	Work Trip Fuel Cons. (Gal/Day)	WORK TRIP AUTO EMISSIONS (kg/day)		
	DRIVE ALONE	SHARED RIDE	TRANSIT	VANPOOL			HC	CO	NO_X
BASE (AVG/TRIP)	0.78	0.19	0.03	0.0	12.80	1.05	0.13	1.85	0.05
POLICY									
1. Employer Carpool Promotion (≥ 250 employees)	-1.5%	6.8%	- 6.6%	-	-0.75	-0.64	-0.66	-0.58	-0.80
2. Employer Carpool Promotion (≥ 50 employees)	-2.9	13.0	-10.1	-	-1.4	-1.22	-1.28	-1.11	-1.50
3. Preferential Parking Employer Carpool Promotion (≥ 50 employees Vanpooling (≥250 employees, ≥10 miles)	-4.4	11.1	-11.0	(.02)*	-4.2	03.15	-3.06	02.84	-3.97
4. Preferential Parking Employer Carpool Promotion (≥ 50 employees) Vanpooling (≥250 employees, ≥ 5 miles)	-6.6	8.1	-12.6	(.04)*	-6.52	-4.91	-5.09	-4.92	-5.76
5. Employer Subsidized Transit Fare Subsidy (50%)	-0.1	-0.3	5.4	-	-0.11	-0.12	-0.11	-0.12	-0.09

* New Share

TABLE 5-9 (continued)

VMT Reduction Potential of Employer-Based Ride Sharing

% Change from Base, Areawide

	WORK TRIP MODE SPLIT				Work Trip VMT (Miles/Day)	Work Trip Fuel Cons. (Gal/Day)	WORK TRIP AUTO EMISSIONS (kg/day)		
	DRIVE ALONE	SHARED RIDE	TRANSIT	VANPOOL			HC	CO	NO_X
BASE (AVG/TRIP)	0.78	0.19	0.03	0.0	12.80	1.05	0.13	1.85	0.05
Policy									
6. Employer Subsidy of Transit Fare (100%)	-0.2%	-0.7%	11.3%	-	-0.23	-0.25	-0.23	-0.24	-0.20
7. Combination of Policies 3 and 5	-0.45	10.8	-6.0	(.02)*	-4.30	-3.25	-3.16	-2.94	-4.05
8. Preferential Parking Employer Carpool Promotion Carpool parking and cost subsidy (≥ 50 employees)	-4.4	19.5	-12.1	-	-2.34	-2.03	-2.10	-1.86	-2.49

*New Modal Share

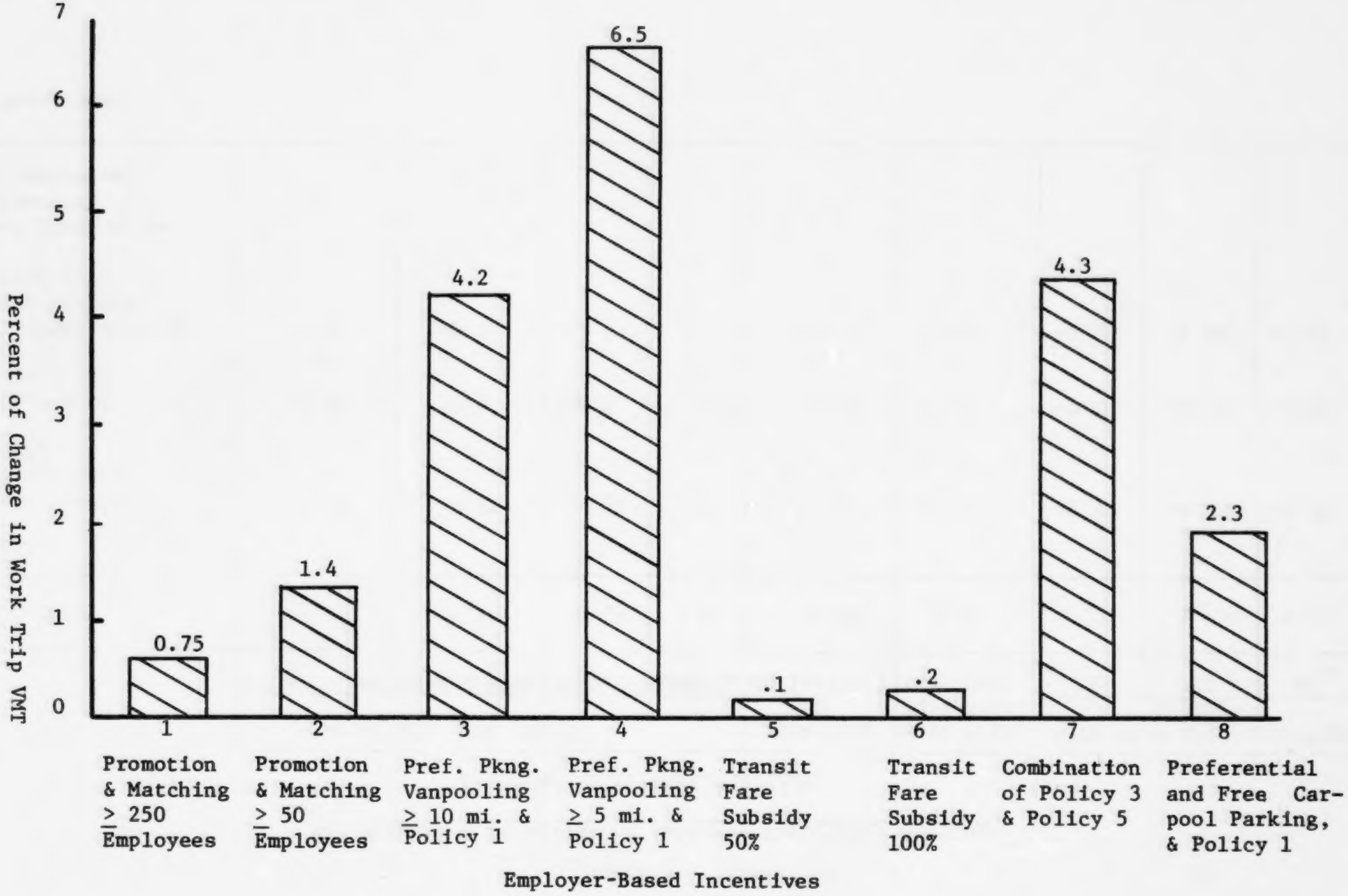

FIGURE 5-1

Work Trip VMT Reduction Potential of Ride Sharing Strategies

2) Given that work trip VMT constitutes 37 percent of total daily travel, a 1.4 percent decrease in work VMT implies a reduction in total daily travel of approximately .5 percent (assuming no increase in non-work travel resulting from a car left at home).

3) Reductions in fuel consumption and in CO and HC emmissions are slightly less than the VMT reduction because of engine cold start effects. In addition, vehicle fuel economy decreases as vehicle occupancy increases (by approximately 5 percent for each 150 pounds of increased vehicle weight).

4) While carpooling strategies may divert some commuters from transit as well as from the drive-alone mode for Denver, this is a relatively small effect given the already-low 3 percent transit modal share. The application of employer incentives to all Denver firms having more than 50 employees decreases transit utilization by 10 percent or an absolute decrease in modal share of .3. In comparison, the drive-alone share decreases by 2.9 percent or a net charge of 2.2.

5) Several mechanisms can be utilized in a ride sharing program to encourage transit ridership as well as ride sharing. One possibility simply is not to offer carpool incentives to persons already well served by transit. Another is for an employer to provide a transit fare subsidy of 50 percent (as is now being done by some firms in Denver) or even 100 percent. The availability of a 50 percent subsidized transit fare increases transit ridership for work trips by 5.4 percent, resulting in approximately a .1 percent decrease in work trip VMT. A fully subsidized transit work trip fare would increase transit utilization 11.3 percent on an areawide basis. Those benefiting the most from

the 50 percent transit subsidy are low income families (+8.2 percent transit use), suburban residents (+7.9 percent) and one-car families (+7.7 percent).

6) Vanpooling constitutes a modal alternative that can supplement existing employer-based ride sharing programs. When vanpooling is made available to those workers having a one-way commute of greater than ten miles and who are employed by firms having 250 or more employees, a 4.2 percent reduction in work trip VMT is forecast compared to a 1.4 percent reduction when only carpooling incentives are provided (Policy 2). The resulting areawide vanpool modal share of 2 percent is two-thirds of that presently existing for transit. If vanpooling is extended so that it is available for one-way work trip lengths of five miles (generally well below the economic break-even point), reductions in work trip VMT of 6.5 percent are achieved (Policy 4). When vanpooling is combined with the 50 percent transit fare subsidy, work trip VMT savings are increased from 4.2 to 4.3 percent. More importantly, however, a much smaller reduction in transit ridership occurs, 6 versus 11 percent.

7) In addition to promoting carpooling, employers can provide additional, more tangible incentives. Two such possibilities are preferential and free carpool parking. Using these incentives in all firms having 50 or more employees in combination with promotion and matching (Policy 2) increases the change in shared ride from 13 to 19.5 percent. A corresponding decrease in work trip VMT is achieved, -2.3 versus -1.4 percent for the case when no special carpool parking incentives are provided.

SUMMARY OF FINDINGS

1) Employer-based ride sharing strategies, as are being implemented in Denver, can be characterized as voluntary incentives rather than disincentives, and producing user benefits in fuel cost savings alone that are over three times greater than the annual program costs of approximately $110,000. As such, ride sharing has proven to be acceptable--and in some cases, highly popular--by commuters, employers, and government in a cultural and physical context that in most other ways is oriented around use of the drive-alone automobile.

2) Colorado's Air Pollution Control Commission's Regulation No. 9 was an important and innovative early national effort in establishing a legal basis for employer-based ride sharing and in converting from an area-wide carpooling orientation to one based on employer initiatives. This regulation, issued in 1974, requires all public and private employers which employ more than 50 employees at one time at one site to provide "incentives to encourage the use of carpools and carpooling, bicycle use, and the use of mass transportation services". The regulation affects 59 percent of the total Denver area commuting trips and 22 percent of total daily travel. By mid-1976, 424 or 54 percent of the 788 employers subject to these requirements either had an approved ride sharing plan or approval was pending. It is estimated that about 60 percent of these employers are utilizing the carpool matching service provided by the Denver Regional Council of Governments; the remainder provide their own matching. About 35 firms are characterized by the Air Pollution Control Division as being "aggressive" in their ride sharing promotional activities.

3) While APCD, DRCOG, and RTD have made important contributions to Denver's ride sharing activities, major successes are largely the result of private initiatives. Prior to EPA promulgation of a Denver TCP, students at George Washington High School developed a carpool computer matching program in response to the 1973 fuel shortages which was implemented by 12 area firms. The program was subsequently adopted by Downtown Denver, Inc. as the basis for their 1974 carpool promotional campaign and made available to all interested Denver employers. It was this set of largely private actions which served as the basis for APCC's Regulation No. 9.

4) A systematic evaluation of the results of Denver's governmental ride sharing programs is fraught with difficulty because of problems in data collection, changes in employment size, unknown incentives, and a declining perception of an energy crisis. The most accurate assessment is "mixed" with some firms demonstrating increases in ride sharing modal share in the range of 40-80 percent while many others report lower carpool utilization in 1977 than in 1975. In some, the absolute number of carpoolers has grown by a small amount, while the overall carpool modal share has remained approximately constant at 19 percent.

5) A major by-product of the ride sharing program is promotion of an increased awareness of alternative transport modes to the drive-alone auto and an increased understanding of air quality and energy conservation issues. These by-products may, in fact, be more important in the long run than the 1-3 percent savings in worktrip vehicle miles of travel which would result from an aggressively promoted carpooling program.

6) The administration of governmental ride sharing programs in Denver can be characterized in terms such as passive, service, matching, second priority, enforcement and annual reporting. APCD and DRCOG, from an employer perspective, each have assigned one full-time professional to fulfill their assigned Regulation No. 9 responsibilities, and this is not nearly sufficient to maintain even a minimal working relationship with several hundred individual employers. The concepts of promotion and marketing are not natural, and possibly not even feasible, to agencies such as DRCOG and APCD. Given the innovative nature of APCC Regulation No. 9 and its implied, non-quantitative "process" standards, APCD has been understandably reluctant to enforce (or promote) a program which contains a certain amount of uncertainty and the potential for something less than a universal acceptance among employers. This is especially the case when APCD's own primary program of vehicle inspection and maintenance has been highly and publicly controversial, has only recently been accepted by the Legislature, and has resulted in a Division "credibility gab" of major proportions. For its part, DRCOG has not wished to be closely associated with a state environmental program which imposes requirements on local employers. Similarly, given the voluntary and community basis of the DRCOG organization, they have felt it was inappropriate for them to aggressively promote carpooling to anywhere near the degree that other efforts have shown is necessary in order to be successful.

7) Ride sharing should be viewed in a framework that is sufficiently broad to include vanpools and transit as well as carpools. At least three Denver employers, along with RTD, have initiated modest vanpool programs, and the Colorado Department of Highways is initiating a vanpool demonstration program to enable private employers to take advantage of front-end funding made available by the Federal-Aid Highway Act of 1976. Of eight possible ride sharing programs analyzed, employer-based vanpooling was the most effective, achieving a potential areawide modal share of 2 percent and a decrease of 4.2 percent in daily work trip vehicle miles of travel.

8) The effectiveness of APCD, DRCOG, RTD, and CDH ride sharing efforts would be considerably enhanced by a program having the following characteristics:

- is coordinated and managed as a single, unified effort,
- is broadened to include vanpooling,
- is oriented basically to marketing and promotion,
- is adequately and professionally staffed,
- places attention on continuity, maintenance, and follow-up, not just on initial, one-time efforts. Many employers have cited as their primary difficulty the problems associated with employee turnover, growth, and layoffs.

9) The existing Denver ride sharing activities can serve as an excellent base for an expanded and coordinated program which is directed not only at air quality but also energy conservation and transportation system management.

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CHAPTER 6

PREFERENTIAL TREATMENT FOR HIGH OCCUPANCY VEHICLES

PREFERENTIAL TRAFFIC CONTROL

A wide variety of techniques can be used to give high-occupancy vehicles (buses, carpools and vanpools) preferential or separate treatment over low-occupancy cars. As included in the Denver and other metropolitan area transportation control plans, their main objective has been to provide reduced travel time for riders of high occupancy vehicles during congested peak hours. This increase in the attractiveness of transit and other ride sharing modes will then induce increased transit and carpool ridership, and thus lower overall vehicle miles of travel.

Traffic control techniques generally considered in this category include exclusive freeway lanes and ramps, preferential surface street lanes, exclusive streets for high occupancy vehicles, and preferential traffic signalization schemes. Exclusive lanes can be either with-flow or contra-flow, and the lane may be either taken from existing roadway space or developed on new right-of-way.

While the primary effect of preferential treatment measures is popularly viewed today as a shift from low to high occupancy vehicles, these facilities can have a number of other important impacts which also may contribute to reduced vehicular emissions. These include reduced congestion and improved traffic operations for all vehicles, increased travel speeds, and increased highway person-carrying capacity.

Preferential treatment facilities were initially developed exclusively for buses, with some form of preferential bus treatments now in operation in virtually all large urban areas of the United States. With the advent of EPA's transportation control plans and the increased emphasis on managing existing transportation systems, attention has expanded to include carpools and vanpools as vehicles qualifying for preferential traffic control, with a carpool occupancy of at least three generally being required. While preferential carpool treatment frequently is associated, by the public and traffic engineers alike, with either the aborted Los Angeles Santa Monica Diamond Lane or the highly successful Washington, D.C. Shirley Highway, in fact many less publicized preferential carpool facilities are now in successful operation throughout the country.

This chapter examines the current status in Denver of preferential treatment measures for high occupancy vehicles, examining in particular the three projects which have been implemented to date:

- 16th - 17th Street bus lanes
- Broadway-Lincoln bus lanes
- Lawrence-Larimer carpool lanes[1]

Several other preferential treatment studies have been performed, with a current emphasis by both RTD and CDH on preferential ramp treatments for buses. In addition, the proposed CBD bus/pedestrian mall is seen as a means of improving both the attractiveness of downtown Denver and CBD transit circulation. The net result is a set of preferential treatment activity that compares favorably with what is occurring in other cities of Denver's size, and provides an excellent opportunity, therefore, to examine both the administrative effort necessary to accomplish successful implementation and the potential of such facilities to contribute to air quality improvements.

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[1] Although the carpool project was very short lived, it nonetheless provides some useful insights on the status of carpooling in Denver, and the relation between carpooling and transit.

In examining the implementation of preferential treatment measures in Denver, it is important to keep in mind the rich traffic engineering heritage of Denver, and both the national and local prestige of the City of Denver's Public Works Department. Perhaps this country's most famous recent traffic engineer was Henry A. Barnes, who served as Denver's traffic engineer during the early 1950's and subsequently moved on to Baltimore and New York. During his tenure in Denver, Mr. Barnes developed the city's one-way street system, the traffic-adjusted coordinated traffic signal system, and the concept of exclusive pedestrian signal phases (the "Barnes Dance"). Emphasis was on the free flow of vehicular traffic, and on maximizing the vehicular capacity of the city's street system. This freedom from traffic congestion, and its implied lack of restriction on the use of the automobile, contributed greatly to Denver's attractive image during the 1960's and early '70's, and to its resultant economic growth during this period. This tradition of traffic engineering continues today, with both the Traffic Engineering Division and Public Works Department being important influences within the city. As described in Chapter 2, the Director of Public Works also serves as Deputy Mayor. The current Mayor was formerly the Director of Public Works and the City's current City Engineer was their former Traffic Engineer.

An important implication of this traffic engineering background with regard to the implementation of preferential treatment facilities is that the orientation to maximizing vehicular flow and minimizing restrictions on the use of the private automobile is well established. A change in emphasis to person movement is by necessity difficult, gradual, and cannot be accomplished without encountering at least some resistance -- a characteristic inherent in any mature agency.

EVOLUTION OF DENVER'S PREFERENTIAL TREATMENT CONCEPTS

The Denver Transportation Control Plan has had an important role in expediting the planning and implementation of preferential treatment facilities in Denver. This section summarizes the legal basis for this work, examining the Colorado Department of Health's 1973 plan submittal, EPA's revision to this plan, and APCC's implementing Regulation No. 9. Subsequent sections then examine in detail the specific project oriented planning and implementation activities which the TCP set in motion.

A characteristic of the TCP which is especially important to preferential treatment measures is that the plan merely calls for the implementation of this concept. Specific facilities, actions, or techniques are not specified. It is left to subsequent efforts to examine alternative implementation possibilities, to determine the feasibility of particular designs, and to gain consensus among the several governmental offices having implementation responsibilities. Even though the capital costs of development and operation are small relative to most transportation programs, it will be seen that this detailed design and coordination concerning the operational characteristics of these facilities has consumed considerable effort.

The initial impetus for the development and implementation of preferential traffic control for high occupancy vehicles came from the State of Colorado Air Pollution Control Transportation Plan prepared by the Colorado Air Pollution Control Division and submitted by the Governor to EPA on May 25, 1973 (1). The State plan proposed the application of preferential traffic control schemes both as a short-term mass transit improvement and as a vehicle use reduction measure. The State plan, however, classified exclusive bus lanes in the "secondary" implementation stage, meaning that the measure was believed to be beneficial but further analysis was needed before implementation. Several observations can be drawn concerning the plan:

- Preferential treatment was proposed for buses only and not for carpools.
- A sensitivity to general traffic congestion issues was exhibited by the plan's proposal to "add-a-lane" for buses through selective prohibition of on-street parking rather than to "take-a-lane" from existing auto traffic. Thus the measure was conceived as a transit incentive rather than an auto disincentive.
- A sensitivity to technical feasibility issues was exhibited by the plan's indication that further site specific analysis would be required as a necessary prerequisite to implementation. Thus, implementation, in effect, was not formally proposed but was considered subject to additional analysis.

As a result of EPA's review of the Colorado plan, supplemental information was requested and in turn submitted by the Governor in July, 1973. The supplemental information, in effect, upgraded preferential treatment schemes as one of the formally proposed VMT reduction strategies, and referred to designation of exclusive lanes for both buses and carpools. EPA's subsequent approval and promulgation on November 7, 1973 of the plan, therefore, required among other steps, that no later than January 31, 1974, the regulations and administrative policies necessary for implementation of bus/carpool lanes be adopted, including the designation of such lanes.

EPA also indicated in the November promulgation that:

> "...There may be some costs (disbenefits) associated with the temporary inconvenience during the travel pattern adjustment period. Some roads will undoubtedly be more congested since in some cases bus lanes will be taken from existing roadways. This congestion will lessen with the passage of time as the shift is made to mass transit."(2)

Though not achieving the EPA mandated schedule, the Colorado Air Pollution Control Commission formally adopted Regulation No. 9 on July 25, 1974 (3) (Appendix B). The regulation contained, in part, the specific administrative provisions with regard to responsibilities for carrying out the detailed preferential treatment studies required by the TCP. These provisions included the following:

- Required Regional Transportation District (RTD) submission of a feasibility study for demonstrating preferential treatments for buses and carpools by September 1, 1974.
- Required RTD submission of a regional plan for establishing preferential treatments by July 1, 1975, including implementation steps, time schedules and costs for implementing this plan by January 1, 1976.
- Required RTD submission of plan revisions and additions by October 1 of each year.

PLANNING AND IMPLEMENTATION OF PREFERENTIAL TREATMENT FACILITIES

A substantial level of activity in the planning, analysis, and implementation of preferential treatment projects has occurred in Denver, with the lead in these efforts being taken by Denver's Regional Transportation District (RTD) working closely with the City and County of Denver. Three of these projects have been implemented with two continuing in operation today. The RTD has been the most active and aggressive of Denver's transportation agencies in the pursuit of applying preferential treatments, which they perceive to be a significant public transit improvement and enhancement mechanism. Because RTD proposals until 1977 had involved only the use of city streets and the pre-empting of either existing traffic lanes or on-street parking, the City of Denver's Public Works Department, specifically the Traffic Engineering Division, also has had a major role in developing and refining design details in response to various operational problems.

A major item of concern in the resulting institutional dialogue, as expected, is the balance between preferential bus treatment and the interference with normal vehicular flow. For example, as will be seen in the following discussions of implementation of the three CBD preferential treatment projects, the question of with- versus contra-flow was an important item of debate between RTD and the City Public Works Department with decisions eventually being made to implement with-flow designs. In addition, several other operational aspects became important including bus-stop locations, turning movements, enforcement, and hours of operation.

Recently, various freeway ramp and lane preferential treatment proposals have been receiving attention, and this has brought the involvement of the Colorado Department of Highways. The Denver Regional Council of Governments (DRCOG), as the area's designated metropolitan planning organization, has a natural coordination role to play in relating preferential treatment and traffic operations/control measures to the region's Transportation Systems Management Element. While DRCOG has displayed an interest in becoming a more active participant, to date they have not been substantially involved in Denver's preferential traffic control developments.

The following discussions of significant Denver preferential treatment projects examines the development and detailed traffic operational considerations inherent to each project. Cost, traffic, travel time, modal shift, safety, air quality, enforcement, and other impacts for the projects, for which data are available, are then summarized in the next major section.

The RTD Feasibility Study

The first significant technical analysis of potential preferential treatment sites in Denver was performed in the spring of 1974 for RTD by John J. Gaudette. Entitled "Preferential Treatment for High Occupancy Vehicles in the Denver Metropolitan Area: A Feasibility Study" (4), the recommendations contained in this report have served as the basis for the three projects which have proceeded to implementation and to more detailed design analysis in other cases.

The Gaudette report, submitted to RTD on July 17, 1974, prior to APCC's issuance of Regulation No. 9, identified the best opportunities for application of preferential treatments in Denver, examined alternative techniques for implementing immediate action projects in the CBD and on an arterial corridor serving the CBD, and completed preliminary analyses of concepts for freeway preferential treatments which were felt to deserve additional study (Figure 6-1).

Two preferential treatment projects were recommended for early implementation:

- With-flow exclusive bus-lanes for approximately one mile on 16th and 17th Streets, a one-way pair which is the spine of the CBD.
- Contra-flow exclusive bus lanes for approximately 2.5 miles on Broadway and Lincoln Street, a one-way pair which serves as a major access route connecting the CBD with Interstate 25 to and from the south.

Gaudette further identified short lengths of Lawrence and Larimer Streets, a one-way pair within the CBD, as potential locations for demonstrating exclusive carpool lanes, although no detailed supporting analyses were given in his report.

Gaudette also recommended that two freeway routes in the western sector of Denver, I-70 and 6th Avenue, appeared well suited for bus/carpool lanes and should be the subject of additional engineering feasibility studies.

Prior to submission of his report, Gaudette discussed the findings with major governmental agencies and interest groups. Although not all of the recommendations were unanimously supported, Gaudette perceived a shared commitment to the implementation of some demonstration program to evaluate preferential treatments. While this initial RTD study was performed quickly, it nevertheless contained a substantial amount of technical depth, particularly with regard to surface arterial preferential treatment alternatives, as well as a good grasp of key issues and opportunities.

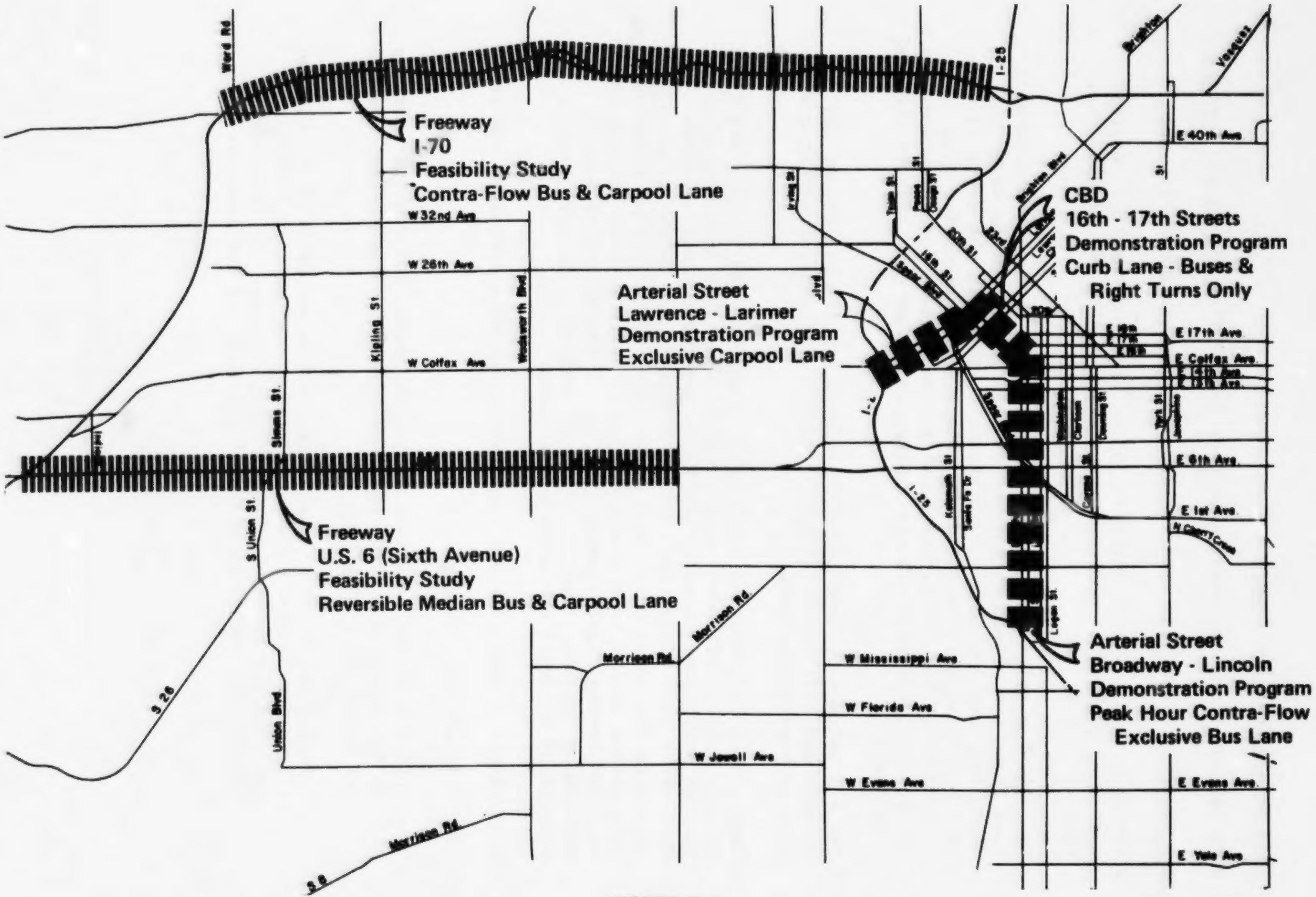

Freeway
I-70
Feasibility Study
Contra-Flow Bus & Carpool Lane
CBD
16th - 17th Streets
Demonstration Program
Curb Lane - Buses & Right Turns Only
Arterial Street
Lawrence - Larimer
Demonstration Program
Exclusive Carpool Lane
Freeway
U.S. 6 (Sixth Avenue)
Feasibility Study
Reversible Median Bus & Carpool Lane
Arterial Street
Broadway - Lincoln
Demonstration Program
Peak Hour Contra-Flow
Exclusive Bus Lane
Ward Rd
I-25
Brighton
Vasquez
E 40th Ave
W 32nd Ave
W 26th Ave
Kipling St
Wadsworth Blvd
W Colfax Ave
Sheridan Blvd
Brighton Blvd
E 17th Ave
E Colfax Ave
E 6th Ave
E 1st Ave
Cherry Creek
Kalamath St
Santa Fe Dr
Logan St
I-25
Simms St
S Union St
Union Blvd
Morrison Rd
W Mississippi Ave
W Florida Ave
W Jewell Ave
W Evans Ave
E Evans Ave
E Yale Ave
S 26
S 8
Indiana

FIGURE 6-1

Preferential Treatment for High Occupancy Vehicles in the Denver Metropolitan Area

Source (4)

16th and 17th Street Bus Lanes

With respect to preferential treatment feasibility within the Central Business District, important Gaudette findings include the following:

- The 16th - 17th Street corridor is the spine of the CBD. Approximately 50 percent of CBD employement lies within one block either side of this spine.

- Over 150 bus trips operate in the CBD during morning and afternoon peak hours and almost 75 percent of the CBD bus routes were consolidated onto the 16th - 17th Street corridor in the early 1970's. In the 1970 Denver Transit Study, the stated reasons for this consolidation were to better serve the employment concentrations and to make more feasible the implementation of some bus-preferential treatments.

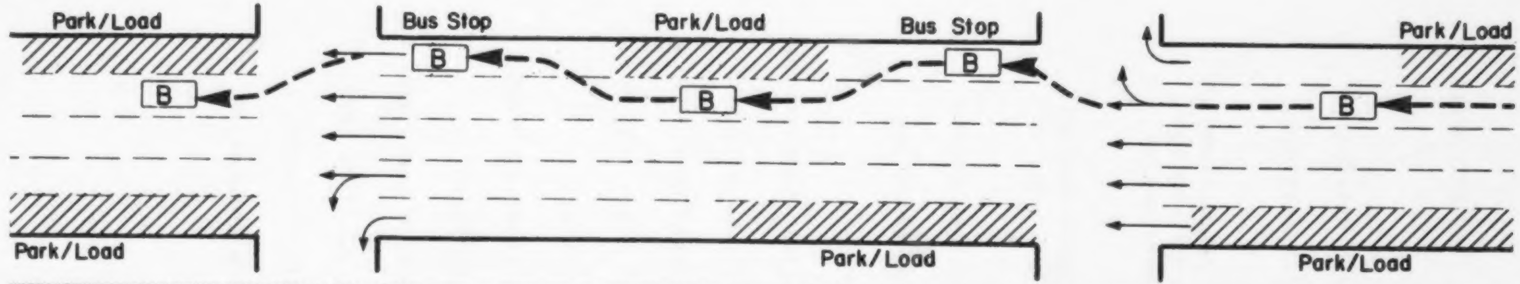
- The bus volumes on 16th and 17th Streets are the highest of any CBD streets and well above the levels required to warrant either a with-flow or contra-flow lane.

- Many of the intersection approaches in the CBD and on 16th and 17th Streets operate with dual-right turn or dual-left turn movements to provide sufficient capacity for heavy turning movement demands. The dual-right turn situations present difficult and delay-producing maneuvers for buses which must weave back and forth from right-curb lane pickup points to the second lane in order to pass through intersections having right-turning traffic. These necessary weaving maneuvers, in turn, cause interference and delay to auto traffic attempting to avoid the maneuvering buses.

Two alternative with-flow bus lane techniques were evaluated and are illustrated schematically in Figure 6-2.

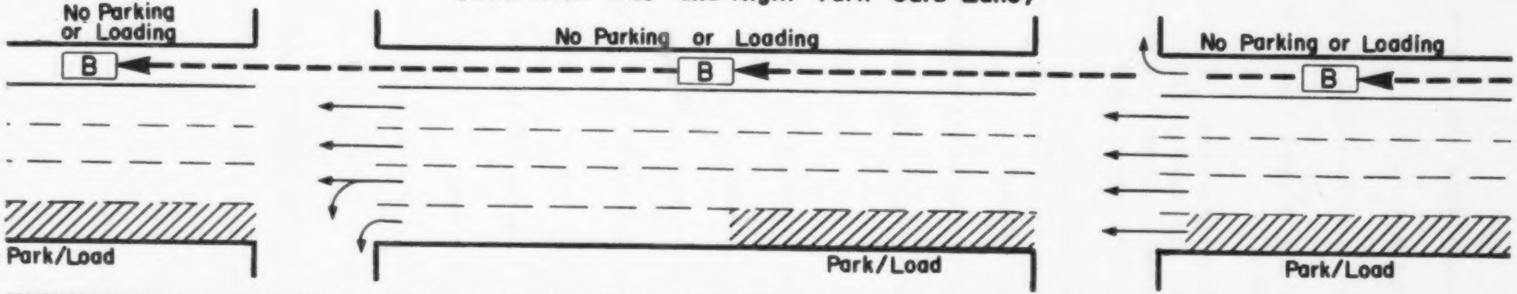
- Option 1 was to eliminate dual-right turns and prohibit parking in the right curb lane, with the right curb lane being reserved for buses and right turns;

- Option 2 was to retain dual-right turns and prohibit parking on right-turn blocks. The second lane from the curb would be reserved for buses and optional right turns. On left-turn blocks, the curb lane would be reserved for bus loading.


Park/Load
Bus Stop
Park/Load
Bus Stop
Park/Load
B
B
B
B
Park/Load
Park/Load
Park/Load

OPTION I

(Exclusive Bus and Right Turn Curb Lane)


No Parking or Loading
No Parking or Loading
No Parking or Loading
B
B
B
Park/Load
Park/Load
Park/Load

OPTION II

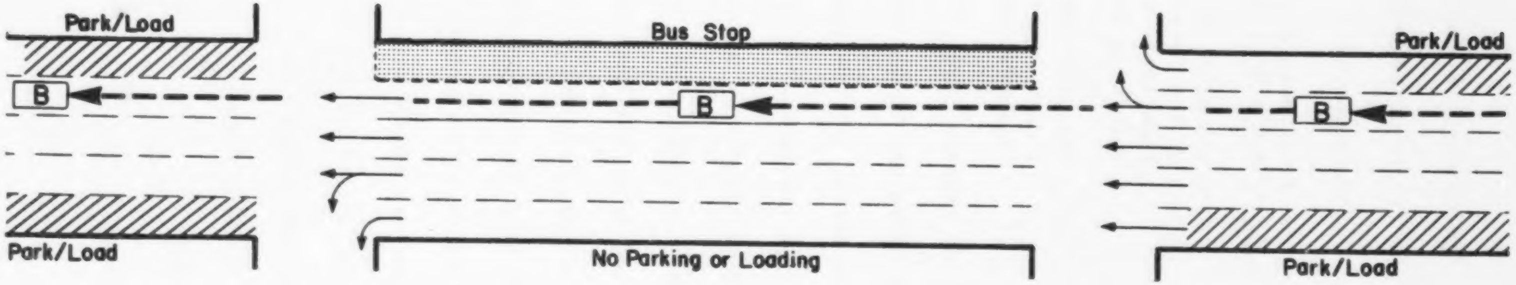

Park/Load
Bus Stop
Park/Load
B
B
B
Park/Load
No Parking or Loading
Park/Load

FIGURE 6-2

Exclusive Bus Lane Options within the Denver CBD

Source (4)

The concept of contra-flow bus lanes was opposed by the City of Denver in that it presented several problems:

- longer lead time required for detailed planning and design;
- the need for reanalyzing signal timing which, while feasible, would be time consuming;
- the need for stringent enforcment of no-stopping regulations in the lane (however, the report failed to note that contra-flow lanes with high bus volumes are inherently more self-enforcing than with-flow lanes); and
- the need for alternative provisions for goods loading and mail pickup. (It should be noted that this is a problem, too, in implementing with-flow lanes.)

It appears clear that the most important reason for rejecting contra-flow lanes was that significantly longer lead time would be required for development, and the desire was for very rapid implementation.

On the basis of intersection capacity analyses, and special observations of dual right-turn locations which showed relatively low levels of utilization of the optional right turn from the second lane, it was concluded that Option I was the more feasible of the with-flow alternatives. This option was proposed to operate on a 24-hour basis but with loading operations permitted in the off-peak hours. The necessity for off-peak buses to weave around vehicles stopped for loading was considered to not significantly hamper bus operations. These design characteristics for the 16th and 17th Street with-flow bus lanes were made operational on December 2, 1974, less than six months after submission of Gaudette's feasibility study report, making this the first preferential treatment project to be implemented in Denver.

Broadway-Lincoln Bus Lanes

With respect to opportunities and techniques for preferential treatments on surface arterials, important RTD study findings were the following:

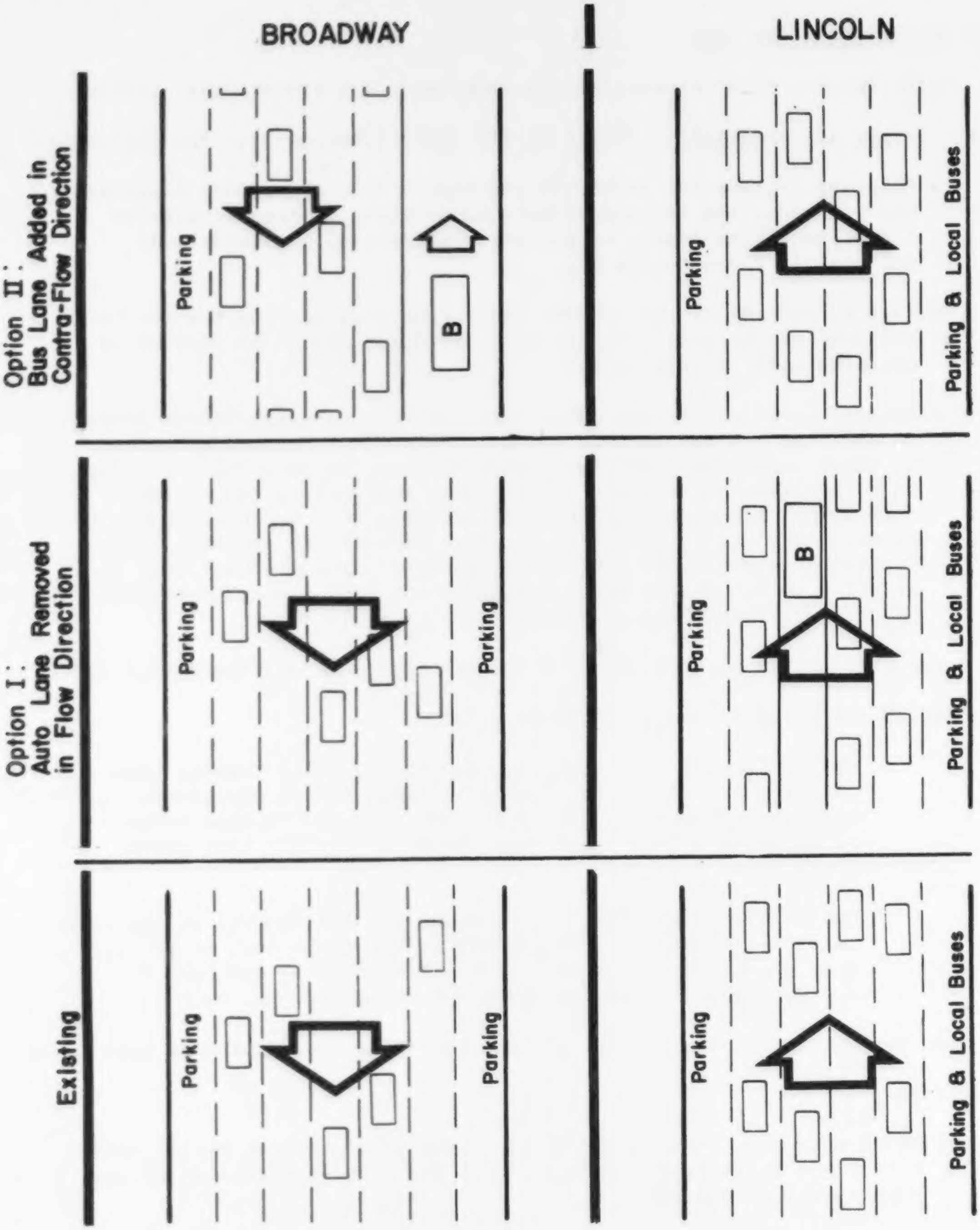
- Existing express bus routes in the Denver area are widely dispersed and opportunities for significant route consolidation to develop bus volumes high enough to warrant preferential treatment exist only fairly close to the CBD.
- Over 60 percent of the express bus routes originate in the southeast quadrant of the area, thus primary attention should be focused on opportunities in this sector.
- Several parallel one-way pairs serve as major traffic access routes to and from the CBD to I-25 and points to the south and southeast. Of those candidates, Broadway, with five moving lanes plus parking on both sides, and Lincoln Street, with four moving lanes plus parking on both sides, are the only streets that are wide enough to provide adequate flexibility and spare capacity to accommodate preferential lane schemes. The other candidate streets have only two or three moving lanes; hence assigning one lane for exclusive bus use would severely reduce capacity for general traffic.

Two alternative peak period preferential treatment configurations were considered for Broadway/Lincoln (Figure 6-3):

- Option I, with-flow exclusive bus lanes, would require removal of one auto lane in the peak direction, but no additional parking prohibitions. The with-flow lane for express buses would be in a lane other than the right traffic lane where local buses operate.
- Option II, contra-flow lanes, would require removal of one auto lane plus prohibition of parking in the right curb in the off-peak direction to accommodate an AM northbound bus lane on Broadway and a PM southbound bus lane on Lincoln.

In evaluating these alternatives, the following considerations were identified:

- The contra-flow lanes would be less disruptive to peak period capacity since there is spare capacity in the offpeak direction street both in the AM and PM.


Existing
Option I: Auto Lane Removed in Flow Direction
Option II: Bus Lane Added in Contra-Flow Direction
BROADWAY
LINCOLN
Parking
Parking
Parking
Parking
Parking
B
Parking
Parking
Parking & Local Buses
Parking
B
Parking & Local Buses
Parking
Parking & Local Buses

Source (4)

FIGURE 6-3

Exclusive Bus Lane Options: Broadway-Lincoln Corridor

- The contra-flow lane is inherently self-enforcing when bus volumes are as high as those anticipated (less than one minute bus headways). On the other hand, with-flow bus lane enforcement would be more difficult and require either stringent enforcement or high levels of voluntary compliance.
- Safety problems are expected to be minimal on with-flow lanes except that some conflicts may arise due to autos weaving across the bus lane. Concerns about safety are greater on contra-flow lanes, particularly with respect to potential hazards to pedestrians. However, safety experience on existing contra-flow lanes in other cities has been relatively good.
- With existing progressive signal timing, with-flow express bus lane operations may actually be faster than contra-flow operation by approximately two minutes over the 2.5 mile corridor. Signals could be retimed to overcome this problem with contra-flow operation (but peak direction auto travel times would probably be negatively impacted to some degree).
- Traffic control signing and signaling would be significantly more complex for contra-flow lanes than for with-flow lanes.

On balance, the easier enforcement and limited impact on other traffic associated with the contra-flow lanes were considered by RTD to be the more important factors and led to their recommendation of this alternative. The traffic engineering problems were considered to be feasible to solve and the potential difference in safety was not considered to be either certain or significant.

The contra-flow lane recommendation, though, was the subject of considerable debate by others, particularly with respect to potential safety hazards, costs, and time required for overcoming the traffic engineering and control problems. The City Public Works Department (Traffic Engineering Division) believed that with-flow lanes were more technically feasible, less expensive, and less risky to implement, and yet would provide similar operational benefits to mass transit as would the contra-flow lanes. Through a series of meetings involving RTD, the City and County of Denver, the Mayor, and other agencies with an interest in the implementation details, it was decided to install with-flow bus lanes.

The decision-making process and preparation of design details consumed a considerable period of time and implementation was achieved on October 20, 1975, approximately 15 months after the submission of the Gaudette report. This is still considered an expeditious implementation of the project considering the complexity of the project and the need to work out differences of technical opinion.

The initial implementation of the project comprised the following characteristics:

- On Lincoln Street, the bus lane was in the right curb lane from the southern terminus near I-25 to 6th Avenue, and then in the right traffic lane (next to the parking lane) from 6th Avenue to 14th Avenue. The preferential lane was initially reserved for buses and right turns from 7 - 9 AM. No significant changes in parking regulations were necessary, since parking already was prohibited between 7 - 9 AM on the right curb lane of Lincoln from I-25 to 8th Avenue. Metered parking was permitted on both sides of the street after 8 AM between 8th Avenue and 13th Avenue both before and after implementation.

- On Broadway, the exclusive express bus lane was in the third lane from the right between 14th Avenue and First Avenue, with a general traffic and local bus lane and the curb parking lane to the right of the express bus lane. Between First Avenue and the southern terminus, the express bus lane was located in the second lane from the right, with the curb lane used by general traffic and local buses. Parking regulations were basically unchanged with parking permitted on both sides of the street between 13th and First Avenues and prohibited in the right curb lane between First Avenue and I-25. The exclusive express bus lane initially was reserved from 4 - 6 PM on Broadway.

- On Lincoln, the express and local buses used the common reserved lane, which also was shared with right-turning vehicles. On Broadway, the express bus lane was segregated from all other traffic including local buses.

Two major changes in the operation of the Broadway preferential lanes were made during the first six months of operation:

- After approximately three months, based on observations by and consultation among RTD, City and County Traffic Engineering, the Police Department, and an evaluation consultant, it was decided to change the times of operation of the preferential lanes to 7 - 8 AM on Lincoln and 4:30 - 5:30 PM on Broadway. These one-hour periods contained the vast majority of express bus trips made in the corridor.

- Throughout the early months of operation, the City and County Traffic Engineering Division became increasingly concerned over the problems they observed in the operation of the Broadway exclusive express bus lane.

    - Automobile drivers felt intimidated when attempting to use the right traffic lane -- sandwiched between the express bus lane and the curb or the parking lane.

    - Although not originally planned, some express buses made limited stops along Broadway. This necessitated potentially dangerous weaving maneuvers by express buses through the right-hand traffic lane. These maneuvers plus local bus operations made the right traffic lane very undesirable for general auto traffic; hence, the effective number of lanes for general through-traffic flow was essentially reduced to three.

    - The necessity for auto traffic to weave across the exclusive bus lane in order to prepare for turns occurred with high frequency. The lane also was used frequently by autos as a passing lane. These problems made effective enforcement of the exclusive lane on Broadway increasingly difficult.

In light of these problems, a decision was made to modify the location of the Broadway bus lane, moving it to the right-most traffic lane (i.e., the lane next to parked vehicles from 14th to First and the curb lane from First to I-25. The change was executed on April 20, 1975. This change made the Broadway bus lane analagous to the one on Lincoln, with a mixture of express and local buses and right-turning traffic all using the same lane.

Lawrence-Larimer Carpool Lanes

The third preferential treatment project implemented in Denver was the Lawrence-Larimer one-way pair exclusive lanes for 3+ occupant carpools. These with-flow lanes were initiated on January 8, 1975, approximately one month after the 16th and 17th Street bus lanes were made operational.

While these lanes were included in Gaudette's RTD feasibility study, RTD has always felt that carpools and transit should not be allowed to use the same preferential area. Their reasoning is that the additional carpool vehicles interfere with bus movements and reduce the operational benefits to bus travel that otherwise would be provided by the exclusive lane.

The City Public Works and Police Departments only reluctantly agreed to the 16th and 17th and Broadway-Lincoln bus lanes, and strongly opposed any implementation of exclusive carpool lanes. The Police Department felt it would not be possible to equitably enforce an arterial street carpool lane. When implemented, adequate police enforcement was not provided and this may have contributed further to violation problems. From a traffic engineering perspective, the Public Works Department felt the lanes would interfere with normal vehicular traffic movements and, while no detailed analysis was performed, the number of possible carpools was not felt to justify this interference.

The Lawrence-Larimer lanes were located in the left curb lanes on both streets, lanes formerly assigned to general traffic movement. The preferential sections were short ones, extending from 9th to 16th Avenues on Lawrence Street in the AM peak period, and from 8th to 13th Avenues on Larimer Street in the PM peak period. The carpool lanes were configured in such a manner that no tangible benefits were provided to carpools while general traffic operations were disrupted. Given the orientation of Lawrence relative to the CBD (Figure 6-1), movements from Lawrence into the CBD are from the right lanes. With only a five-block length and the need to be on the right side of the street to accomplish required turns, there was little or no incentive for carpools to travel within the left-hand lanes. With these operational difficulties, combined with the lack of support from the City, the Lawrence-Larimer carpool lanes operated for only a short period of time.

I-70/U.S. 6 Preferential Treatment Feasibility

While the Gaudette/RTD analysis concluded that the most immediate and largest benefits of preferential treatments for buses would occur within the downtown area, it was felt two limited access facilities on the west side of the City also might prove to be feasible for some kind of preferential treatment and therefore were deserving of further study: The I-70 freeway and U.S. 6/Sixth Avenue Freeway (Figure 6-1).

This also provided the opportunity for the Colorado Department of Highway's District 6 office to become an active participant in Denver's preferential treatment activities. This office's involvement with freeway surveillance systems began with the installation in 1973 of a Honeywell computer to monitor traffic flow conditions along approximately twenty directional miles of I-70 and I-25. The system presently is used as a basis for the selection of messages to be placed on the network's four freeway variable message signs (which also are under the control of the same computer) and to collect traffic volume data for various traffic flow analyses. Since the CDH Denver installation currently is not being used to its full capacity, it provides an excellent base to perform surveillance of additional miles of freeway or to coordinate the operation of area-wide entrance ramp metering signals or other control devices.

Gaudette's preliminary analysis of the feasibility of freeway preferential lanes on I-70 produced the following findings:

- Because of relatively low volumes of existing and potential future buses on freeway routes in Denver, any freeway preferential scheme would have to include carpools as well as buses to meet any reasonable criterion for implementation.
- In order for with-flow lanes to be feasible, the percentage of vehicles with 3+ occupants would have to triple from the existing level of 5 percent to 15 percent. This corresponds to an increase in average auto occupancy from the existing 1.38 per car to 1.60 per car. The possibility of this occurring was considered remote and the with-flow freeway lane concept was rejected.
- In order for contra-flow lanes to be feasible, the percentage of vehicles with 3+ occupants would have to double from the existing level of 5 percent to 10 percent. This corresponds to an increase in average auto occupancy from 1.38 to 1.49. Serious questions have been raised, however, concerning the safety impact of allowing carpools to use a contra-flow lane. In any event, additional study of the impact of this concept and other alternatives was recommended.

The Sixth Avenue Freeway was suggested as a good route on which to construct lanes in the median for buses and carpools. One reason given for the feasibility of such a concept on the recommended 6.6 mile outer section of the freeway (from I-70 to Sheridan) was that there is only one freeway underpass, making the construction of a median way simpler than on other freeways. (It was not mentioned, however, that this section of the Sixth Avenue Freeway is not subject to recurring peak period congestion whereas parts of the remaining section between Sheridan and I-25 have heavier traffic demand and more frequent and severe congestion.)

In July, 1975, the Colorado Department of Highways initiated a contract with Wilbur Smith and Associates to investigate in more detail the preliminary Gaudette/RTD recommendations for bus and carpool preferential treatments on the I-70 and U.S. 6 facilities. Completed in September, 1976 (5), the study concluded that no exclusive median alternatives could be justified in the Sixth Avenue corridor due to constrained rights-of-way, severe disruption and environmental consequences of acquiring additional rights-of-way, and high construction costs. The idea of bus and carpool contra-flow lanes also was rejected due to safety considerations. It has become generally accepted that carpools should not be permitted in freeway contra-flow lanes unless a buffer lane can be provided to separate the contra-flow traffic from the opposing stream, and this is considered infeasible on a freeway with only three lanes in each direction. Other major findings include the following:

- Ramp metering, with bypass lanes for buses and carpools, is the most feasible preferential treatment alternative for both the I-70 and Sixth Avenue corridors. It offers the advantage of handling more automobile traffic demand on the freeway than either with-flow or contra-flow lane alternatives, and still provides substantial travel time advantages to buses and carpools.[1] It also provides optimum controllability of traffic conditions in the freeway corridor via increasing or decreasing the metering rates in response to future changes in traffic demand patterns.

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[1] The study, however, assumed a constant level of demand for each alternative. Specifically, it was estimated that three or more person carpool and bus ridership would approximately double between 1975 and 1980 due to transit improvements, carpool encouragement and responses to congestion. This is considered an invalid assumption and the weakest link of the analysis. It is known that carpool and bus ridership are affected to some measurable degree by the kind of preferential treatments implemented. Those techniques providing larger travel time advantages for high occupancy vehicles induce greater mode shifts. In addition, "visibility" of the preferential treatment has been shown to influence the magnitude of the demand shift.

- Implementation of with-flow lanes on the I-70 and Sixth Avenue mainlines is not practical at this time, in part because of prevalent public attitudes against disincentive measures which severely degrade level of service for low-occupancy vehicles.
- Discontinuity of CBD ingress and egress to and from each of the corridors, and geometric and operational problems at the interchanges of the routes with I-25 create difficulties in implementing preferential mainline treatments.

Ongoing Preferential Treatment Planning Activities

Based both on the successful implementation of the CBD and arterial preferential bus treatments and the recommendations of the Wilbur Smith study of I-70 and 6th Avenue freeway preferential treatments, Denver is continuing its pursuit of other preferential treatment opportunities in several ongoing planning activities. These activities illustrate a growing acceptance of the potential applicability and benefits of preferential treatments among the agencies responsible for Denver's transportation system. Hence, it appears that while the air quality Transportation Control Plan served as a significant catalyst in initiating preferential treatment project development, efforts have not stopped with a one-shot response to the TCP.

The following paragraphs summarize activities concerning metering and bus priority at freeway ramps. Other major actions involving preferential treatment are the proposed 16th-Street Pedestrian/Bus Mall and the series of on-going RTD corridor studies oriented around East Colfax Avenue, Santa Fe Drive, and other major transit routes. These latter activities are described as part of Chapter 9, Transit Improvements.

Metering of Freeway Ramps

The Colorado Department of Highways is pursuing further evaluation of ramp metering and priority entry for high-occupancy vehicles, in line with the Wilbur Smith recommendations. They have obtained the FREQ3CP model developed by the University of California at Berkeley, attended workshops to learn how to use the model, and are in the process of preparing input data for testing alternative freeway entry control strategies. The CDH five-year Capital Program has funds budgeted for implementation of a freeway control project. According to CDH, the plan is to make systematic progress in freeway entry control, beginning with selected isolated locations and working toward coordinated ramp control systems along corridors. In our judgment, three to five years is the likely time frame required for substantive progress in freeway corridor control even if the plan is pursued fairly vigorously by CDH.

Bus Priority at Freeway Ramps

RTD has devised a concept for bus priority for high volume freeway exit ramps at signalized diamond interchanges. This concept involves building a short bus lane near the exit ramp signal to permit buses to bypass long queues of cars waiting to turn left (Figure 6-4). A special bus pre-emption device would be installed in the traffic signal controller to provide a fast and unimpeded left-turn green interval for buses. One such project is being developed at the 104th Street exit ramp from I-25 for use during the afternoon peak period when heavy outbound commuter traffic uses the ramp. Three additional installations on I-25 exit ramps (at Broadway, U.S. 36, and Hampden) and one on the Sixth Avenue Freeway

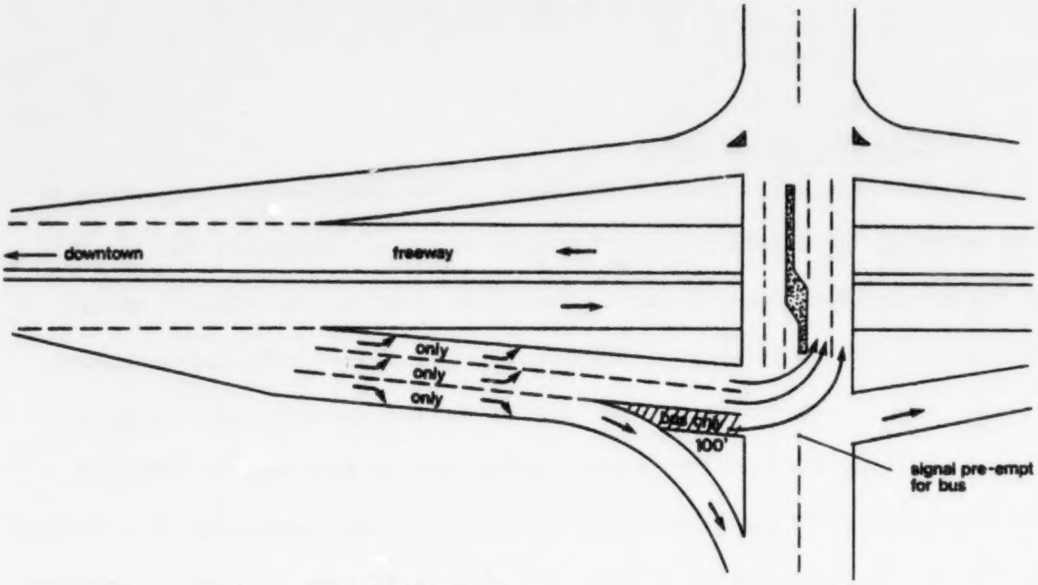
downtown
freeway
only
only
only
bus only
100'
signal pre-empt for bus

FIGURE 6-4

Freeway off Ramp: Bus Congestion Bypass

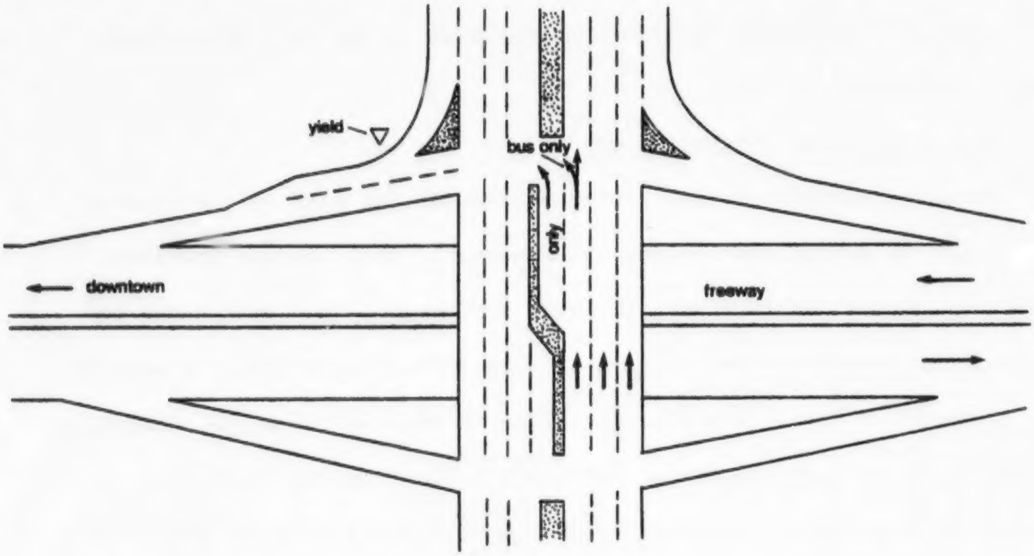
yield
bus only
only
downtown
freeway

FIGURE 6-5

Freeway on Ramp: Bus Congestion Bypass

Source: RTD files

exit ramp at Simms are under design. All of these are intended for afternoon peak period traffic and may save buses as much as 2 to 3 minutes of delay at the height of the peak. Worthwhile benefits to buses are only feasible at exit ramp locations where exit ramp left-turn traffic is delayed for more than one signal cycle; hence, the applicability is limited to a relatively small number of scattered locations in the metropolitan area.

RTD also has devised a somewhat similar concept for giving buses a priority bypass at high volume, high delay signalized diamond entrance ramp left-turn locations. Buses are permitted to turn left from the lane next to the left-turn storage bay to bypass long queues of left-turning cars (Figure 6-5). This scheme is proposed for the I-25 entrance ramp left turn from 104th during the morning peak period when very long queues build up. Delay savings of up to 3 to 4 minutes for buses are expected. This scheme, too, is only applicable at a few scattered interchanges where both long left-turn queues and substantial express bus traffic is present.

SUMMARY OF PROJECT IMPACTS

While considerable progress is being made in Denver in the implementation of preferential treatment facilities for transit vehicles and also of related traffic operations improvements, an important question is the cost of these facilities and the degree to which they are contributing to improved air quality. This section summarizes the operational and associated transportation impacts of the three implemented preferential treatment projects, examining the following specific impacts:

- implementation cost
- transit ridership
- travel time, bus and automobile
- safety
- traffic diversion
- violations and enforcement
- vehicle miles of travel, emissions and energy

The findings are based primarily on the results of evaluation studies conducted under the sponsorship of the City and County of Denver Public Works Department (6,7).[1]

Implementation Cost

Direct costs associated with the implementation and operation of Denver's preferential treatment facilities can be characterized as being very modest. The primary effort has been in the professional staff time required to coordinate design details among the various involved agencies and departments.

16th and 17th Streets - Necessary traffic control was accomplished through the installation of simple and relatively inexpensive signing and marking. Costs estimated by Gaudette were minimal, totalling only $3,200, exclusive of the public information campaign and of planning and design costs.

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[1] Both studies were based on the collection of "before and after" data. The 16th and 17th Street exclusive bus lanes were implemented on December 2, 1974; the before data were collected during November, 1974, and the after measurements were performed in February, 1975. The Broadway-Lincoln bus lanes were opened on October 20, 1975; before studies were performed mainly in May and June, 1975, and the after studies in March and April of 1976. The after studies therefore were under conditions of the original preferential lane use configuration on Broadway and do not address the impact of shifting the bus lane from the second lane to the right hand traffic lane in late April, 1976.

Broadway-Lincoln - The costs of implementing the Broadway and Lincoln preferential lanes project estimated by Gaudette (for contra-flow lanes) totalled $71,000,comprised of $36,000 for traffic control modifications, $13,000 for redesigning and printing schedules for modified express bus routes, $10,000 for the public information campaign, and $12,000 in overhead. Actual costs for developing and operating the Broadway-Lincoln preferential lanes project, as reported by the City Public Works Department were $1000 for implementation and $250 per year for operation, exclusive of both design and enforcement.

Transit Ridership

16th and 17th Streets - Information provided by RTD, summarized in Table 6-1, reveals the high volumes of local and express buses using 16th and 17th Streets in the CBD during peak periods. While bus volume data are shown for two-hour periods in the AM and PM, the vast majority of these buses, particularly the express buses, are concentrated in a one-hour peak period. As a consequence, roughly 100 buses travel on both the 16th and 17th Street exclusive bus lanes during the AM and PM peak hours.

Data on express bus ridership are summarized in Table 6-2 and indicate that average express bus passenger loads on the express buses did not change significantly from one month before to two months after the implementation of the exclusive bus lanes. The overall AM and PM loads averaged approximately 34 riders per bus before and after.

TABLE 6-1

Peak Period Bus Volumes on 16th and 17th Streets

	AM (7-9)		PM (4-6)	
	16th	17th	16th	17th
Express Buses	61	50	58	46
Local Buses	65	62	72	78
Total	126	112	130	124

TABLE 6-2

Average Passenger Loads on Express Buses Using 16th and 17th Streets

	AM	PM
Before		
November 12, 1974	35.2	32.4
November 13, 1974	35.4	33.6
Average	35.3	33.0
After		
February 11, 1975	36.2	32.9
February 12, 1975	37.0	31.8
Average	36.3	31.8

Special CBD boarding and alighting counts made on two of the eight major local bus routes using 16th and 17th also indicated that total bus ridership both throughout the day and in the peak periods had not changed significantly. Peak local bus loads in the CBD averaged approximately 30 riders per bus.

Although the full effect on ridership may not be felt during a two-month period, the evaluation results indicate that transit ridership impacts are not likely to be very significant.

Broadway-Lincoln - The transit patronage impacts of the Broadway and Lincoln exclusive bus lanes are somewhat more encouraging. A large number of express routes were consolidated onto Broadway and Lincoln which affected a near tripling of express bus trips on these streets, Table 6-3. Total patronage on the express lines, though, increased by proportionately greater amounts resulting in average load factor increases of five to seven persons per bus (or about 15 to 25 percent). This increase in patronage was attributed primarily to the express routes which travelled Broadway and Lincoln both before and after the exclusive bus lanes were implemented. For example, PM ridership on the preexisting Broadway express routes increased from 406 to 560 persons, or almost 40 percent. RTD information indicates that patronage on the express lines which were rerouted onto Broadway and Lincoln did not change significantly.

Although the absolute magnitude of the net increase in bus ridership was not dramatic, totaling perhaps 150 riders in each of the peak periods, the bus lanes did appear to induce a measurable increase in ridership.

	Before	After	% Change
Lincoln - 7:00-8:30 AM			
Number of Express Bus Trips	18	47	161.
Total Passengers	556	1,719	210.
Average Load	31	36	16.
Broadway - 4:30-5:30 PM			
Number of Express Bus Trips	15	43	187.
Total Passengers	406	1,475	263.
Average Load	27	34	26.

TABLE 6-3

Express Bus Volumes and Ridership on Broadway-Lincoln

Bus Travel Times

16th and 17th Streets - Table 6-4, based on point-to-point stopwatch timings, indicates that, with one exception, improvements in bus travel time attributable to the bus lanes were very significant. On 17th Street, bus travel times were reduced by 2.5 minutes or more during the morning peak, noon, and afternoon peak study periods, representing a 25 to 30 percent improvement in bus levels of service. This improvement of bus travel time results from general relief of traffic congestion and reduction of interference between buses and autos.

On 16th Street, bus travel times were reduced by about one minute in the morning peak and noon periods, but increased by more than one minute in the afternoon peak. Less traffic congestion existed on 16th Street than on 17th Street in the before case, which helps to explain the smaller effects of the bus lane on bus travel times. The increase in bus travel times in the afternoon peak was attributed to severe bunching of buses at a few critical points and increased right-turn queuing at some of the intersections because of the elimination of dual right turns.

TABLE 6-4

Bus Travel Times

	Before (min:sec)	After (min:sec)	Difference (min:sec)	Percent Difference
16th Street - Glenarm to Larimer				
7:30-8:30 AM	6:02	5:02	-1:00	-16.1%
12:00-1:00 PM	5:56	4:41	-1:15	-21.1%
4:30-5:30 PM	6:26	7:42	+1:16	+19.8%
17th Street - Lawrence to Tremont				
7:30-8:30 AM	8:19	5:51	-2:28	-29.6%
12:00-1:00 PM	9:20	6:28	-2:42	-28.9%
4:30-5:30 PM	11:36	8:47	-2:49	-24.4%
Lincoln - Express				
7:30-8:30 AM	6:53	6:22	-0:31	-7.5%
Broadway - Express				
4:30-5:30 PM	8:23	7:15	-1:08	-13.5%

TABLE 6-5

Automobile Travel Times on 16th and 17th Streets

	Before (min/mi.)	After (min/mi.)	Difference	% Difference
16th Street - Cleveland to Larimer				
7:30-8:30 AM	4.8	4.7	-0.1	-2%
10:00 AM-2:30 PM	7.9	6.1	-1.8	-23%
4:30-5:30 PM	8.3	5.8	-2.5	-30%
17th Street - Court to Larimer				
7:30-8:30 AM	7.1	5.9	-1.2	-17%
10:00 AM-2:30 PM	7.9	6.6	-1.3	-16%
4:30-5:30 PM	9.8	8.1	-1.7	-17%

Broadway-Lincoln - Although the bus lanes on Broadway and Lincoln are approximately 2.5 miles in length, compared to only about one mile for the 16th and 17th Street bus lanes, the improvements in bus travel times were not as great. As summarized in Table 6-4, express bus travel times were reduced by approximately one-half to one minute, or 7 to 14 percent.[1]

	Before (min:sec)	After (min:sec)	Difference (min:sec)	% Difference
Lincoln (7:30-8:30 AM)	7:00	7:16	+0:16	+3.8%
Broadway (4:30-5:30 PM)	7:17	7:05	-0:12	-2.7%

TABLE 6-6

Automobile Travel Times on Broadway and Lincoln

Automobile Travel Times

16th and 17th Streets - Floating car runs were conducted to determine automobile before and after travel times, Table 6-5. During periods of heavy congestion, definite improvements in auto travel times occurred, amounting to about 17 percent on 17th Street during all periods tested, and 23 percent to 30 percent on 16th Street during the midday and PM peak periods. The highest travel speeds occur on 16th Street during the AM peak period and there was only a small change after implementation of the bus lane. During all other times on 16th and at all times on 17th, the travel time improvements are roughly the same as experienced by buses. This helps to explain why no significant mode shifts to transit were realized as a result of the bus lane implementation.

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[1] These improvements were measured when the express bus lane was separate from the right lane used by local buses and right turners. The modification of the bus lane on April 20, 1976, may have resulted in another change in express bus travel times, but no evaluation data have been collected to determine the impact of this action.

Broadway-Lincoln - Table 6-6 summarizes data collected in the peak directions during peak periods on Lincoln and Broadway, showing an increase in travel time of 3.8 percent on Lincoln and a decrease of 2.7 percent on Broadway. However, during the 15 or 20 minutes of greatest AM peak period congestion on Lincoln, substantial delays occurred at the complex intersection with 6th and Speer, resulting in increases in travel time of three to four minutes for some automobiles. It was hypothesized that increases in speeds between intersections in the after case may have made up the time lost due to the increased intersection delay, resulting in no significant change in overall average travel time. In any event, the buses on Lincoln and Broadway appear to have gained an average relative travel time improvement compared with autos of about one-half to one minute as a result of the exclusive bus lanes.

Safety

A fear of increased accidents involving private automobiles, buses and pedestrians was an issue in the development of both the Lincoln-Broadway and 16th-17th Street bus lanes. While the available data do not permit any valid references concerning the safety impacts of these two facilities, increased accidents were not mentioned as a problem in discussions with City and State officials. This is consistent with experience in other cities and countries where safety problems have not materialized with implementation of numerous with-flow priority bus lanes (8,9). For example, the number of accidents in London for 29 with-flow bus lanes decreased by 16 percent based on before and after studies, compared to a 3 percent decrease in all of Greater London during the same period.

No data on traffic accidents were included in the 16th and 17th Streets evaluation, and only very limited data were collected in the Broadway-Lincoln study. Before data from the period of October 20 to December 31, 1974, were compared with the same after period in 1975. The total number of accidents reported on Broadway and Lincoln increased from 281 before to 327 after. However, these statistics should be treated with caution since they include accidents occurring throughout the 24-hour day. No comparisons were given of accident experience during only those hours when the bus lanes are operational, nor was an investigation made to determine bus involvement in or causation of collisions. Consequently, it is felt that the data at hand are not sufficient to develop any Denver-specific conclusions concerning safety impacts of the implemented preferential treatment facilities.

Traffic Diversion

16th and 17th Streets - Results of traffic counts on 16th and 17th Streets, shown in Table 6-7, indicate reductions in traffic volumes after the bus lanes were installed. Reductions were especially significant on 16th Street where volumes dropped between 95 and 335 vehicles per hour depending on time of day and location, though short sample counts made on parallel streets showed no consistent, corresponding increases. Because of the relatively large number of alternative routings, it is difficult to interpret the exact changes in traffic routings which may have occurred, or even of other possible causes of traffic volume reduction.

TABLE 6-7

Traffic Volume Changes on 16th and 17th Streets

Street	Crossing Street	Change in Volume - November '74 - February '75		
		7:00-8:00 AM	12:00-1:00 PM	4:30-5:30 PM
16th	at Court	-145	-145	-235
	at California	-170	-300	-250
	at Arapahoe	-135	-335	-255
	at Blake	-120	-255	-95
17th	at Tremont	-165	+220	+45
	at Stout	-30	-5	-135
	at Lawrence	-120	-40	-260
	at Wazel	-30	-45	-15

TABLE 6-8

Traffic Volume Changes in Broadway-Lincoln Corridor

Period	Street	Location	Volume Change After Bus Lane Installation
AM Peak Hour	Lincoln(NB)	between Ohio & Speer	-100
		between Speer & 14th	-300
	Logan(NB)	between Ohio & Speer	+300
		between Speer & 14th	+100
	Clarkson(NB)	between Ohio & Speer	+200
PM Peak Hour	Broadway(SB)	between Ohio & Speer	-100
	Grant(SB)	between Ohio & Speer	-100
		between Speer & 14th	+100
	Washington(SB)	between Ohio & Speer	+300
		between Speer & 14th	+100

Broadway-Lincoln - Results of the traffic counts in the Broadway-Lincoln corridor are shown in Table 6-8. The most significant changes occurred in the AM peak hour with traffic decreasing from 100 to 300 vehicles per hour on Lincoln and increasing on parallel northbound streets. Lesser diversion occurred in the PM peak hour on Broadway with hourly volumes dropping by 100 vehicles.

Violations and Enforcement

Enforcement of Denver's preferential lanes is the responsibility of the City of Denver Police Department. Approximately 10 percent of the 1385-person force is assigned to traffic, with responsibilities extending to those portions of the interstate system located within the City. The objective of the traffic police generally is seen as accident prevention and "keeping the traffic moving." Any special enforcement of the preferencial lanes has been handled by extended shifts and overtime pay, with costs scheduled to be covered by an EPA grant. The fine for violation of the preferential lanes is $25.00 with an associated four-point driver's license penalty. Tickets are processed by the Court of the County of Denver.

16th and 17th Streets - No documentation is available on the subject of violations and enforcement on 16th and 17th Streets. Interviews with police indicated that the bus lanes on these streets are not treated as a special problem. The curb lane reservation for buses and right turns is largely self-enforcing given the high number of buses using these lanes throughout the day and since autos can gain little or not time advantage by using the lane.

Broadway-Lincoln - Several significant violation and related traffic operations problems existed with the original configuration of the Broadway-Lincoln lanes. The revised lane designs, however, have largely overcome the initial violation difficulties and enforcement is no longer considered to be a major problem by RTD, the police, or the Court.

- There initially was a high frequency of lane violations of the express bus lane on Broadway. For example, during one afternoon between 4:30 and 5:30, 34 express buses and 260 violators were counted in the bus lane. Some of these were undoubtedly due to legitimate weaving maneuvers across the bus lane to prepare for turns, but a substantial number resulted from the tendency of cars to use the bus lane for passing maneuvers. (No observations of violations were made after the Broadway bus lane was moved to the right, but it is believed that the problem has been relieved significantly.)

- On Lincoln in the AM peak hour, the congested right turn at 8th Avenue caused long queues in the bus lane. Right turning cars had to either enter the lane more than one block upstream or cut into the queue near 8th Avenue.

- On Lincoln in the tow-away zones, some parking violations occurred but did not seem to hamper bus lane operation since there were adequate gaps available to weave around the parked cars. Indeed, a tow-away operation could potentially cause more disruption than do the parked vehicles.

- Direct enforcement through issuance of citations is difficult on Broadway-Lincoln because of potential problems of traffic disruption. The enforcement approach used is high visibility of police patrolmen during the peak hours. One man is assigned regularly to Lincoln, with two or three men diverting to the street during the AM peak. Broadway has three to four patrolmen on the street during the peak hours.

A problem contributing to the difficulty of full enforcement on Lincoln-Broadway is the low number of express buses relative to the lane's capacity, thereby resulting in a low visibility of the lane. A feeling that the lane is not being fully utilized makes it difficult to insist on rigid enforcement. Further, violators can claim they are in the lane to make a legitimate right turn. Police have had to locate themselves only in positions where this could not be considered a feasible excuse. Finally, the Court of the County of Denver initially dismissed some, but not all, cases on the grounds that the motorists had not been given sufficient notice or that there was lack of sufficient evidence that the person was not in the lane as part of a turning movement. However, with improved signing, better police location, and the relocated lane locations, there has been a marked decrease in the numbers of violations, contested cases and dismissals.

Lawrence-Larimer - The police purposely avoided attempting to enforce the carpool lanes on Lawrence and Larimer. They considered the scheme to be counterproductive and felt that stringent enforcement would be impractical and highly unpopular. Many carpool vehicles did not use the assigned left lanes because of the lack of significant travel time advantage and the difficulty of weaving back through traffic for right turns. A high frequency of carpool lane violations was reported and the inability to enforce the lane was used as one of several reasons for cancellation of the project.

Vehicle Miles of Travel, Energy and Emissions

16th and 17th Streets - Immediate transit patronage gains were not apparent on the lines using 16th and 17th, though the observations available may not fairly reflect the full effect of the lanes. Since a substantial volume of buses use 16th and 17th and the travel time improvements for bus riders occur throughout the day, the potential VMT impact of even quite small mode shifts is considered greater on 16th-17th than on Broadway-Lincoln. However, since data are lacking, the existence and magnitude of the impact are uncertain.

Documentable impacts on energy and emissions of the 16th-17th bus lane project result from increases in general traffic speed on both streets, estimated to average approximately 20 percent for the period from 7:30 AM to 5:30 PM. The bus lane covers one mile on each street, and the 10 hour volume for the two streets combined approximates 15,000 vehicles per day, or 3,600,000 vehicle miles annually. The overall increase in average speed of 20 percent from 8.2 to 9.9 mph produces an 8 percent improvement in fuel consumption rate from .111 to .102 gallons per vehicle mile. Thus, the estimated annual fuel saving is 32,400 gallons.

Similarly, the speed increase from 8.2 to 9.9 mph causes CO and HC emission reductions of 2.5 percent and 2.8 percent respectively, producing annual reductions of 29,160 pounds and 2,196 pounds.

Broadway-Lincoln - The five-month impact on bus patronage was an increase of approximately 150 riders during both the morning and afternoon peaks. Assuming an average round trip commuting distance of 20 miles for new express bus riders and a former car occupancy of 1.2 persons, the 150 new riders yield a daily VMT reduction of 2,500 miles, or 600,000 miles per year, assuming 240 working days. While this is an almost negligible fraction of areawide VMT, the impact is nonetheless meaningful in absolute terms considering that this is only a single project covering 2.5 miles in each direction. If express bus coverage is further expanded, potential ridership gains and VMT reductions could be several times larger. For example, a 20 percent reduction in bus travel time for work trips to the CBD is estimated to result in a 6 percent increase in transit ridership and approximately 1 percent reductions in drive alone travel, work vehicle miles of travel, and fuel consumption (Chapter 9).

The actual Broadway-Lincoln mode shift and resultant daily VMT reduction of 2,500 miles attributable to the bus lanes is the principal source of reductions in energy use and emissions. Given 2,500 vehicle miles per day, 240 working days per year, and a composite fuel economy of 12.6 mpg, the resulting annual fuel savings is 49,180 gallons.

Similarly, assuming CO and HC pollutant emissions rates of .32 and .022 pounds per vehicle mile, respectively, the annual 600,000 mile reduction would produce emissions reductions of 192,000 pounds and 13,200 pounds.

Much effort has been devoted in Denver during recent years to improving overall traffic operations, with the 16th-17th and Broadway-Lincoln bus lanes representing only two examples. Table 6-9 illustrates the estimated region-wide effects based on a disaggregate travel demand analysis of a 5 percent improvement in all in-vehicle travel times, both peak and off-peak. While this large a change may not be feasible in a city such as Denver, it does imply a target of more than 1 percent, or approximately 11,000 gallons per day in fuel conservation potential just by affecting levels of service, even though total vehicle miles of travel is slightly increased.

TABLE 6-9

VMT, Fuel, and Emissions Potential of a 5% Improvement in In-Vehicle Travel Time

Travel	Item	Percent Change
Work	VMT	-0.01
	Fuel	-1.8
	HC	-0.9
	CO	-0.8
Non-Work	VMT	+0.7
	Fuel	-0.6
	HC	-0.1
	CO	+0.2
Total	VMT	+0.5
	Fuel	-1.1
	HC	-0.4
	CO	-0.24

SUMMARY OF FINDINGS

1) Meaningful progress is being made in Denver in the implementation of preferential treatment facilities for high occupancy vehicles. Two exclusive bus lanes now are operational on surface streets, and several freeway ramp locations have been identified as candidate sites for preferential bus treatment and are in advanced stages of planning. In addition, major feasibility and design studies have been performed on other projects, investigating a wide range of areawide preferential treatment opportunities.

2) The concept of preferential treatment for high occupancy vehicles, however, has been limited in Denver to buses. With the exception of one short-lived carpool lane, current and proposed preferential treatments are limited to bus traffic. This reflects the combination of the absence of freeway locations lending themselves to carpool utilization, and RTD's overall objective of promoting transit development.

3) Preferential treatment facilities and studies have been undertaken to date largely "where the opportunity is available." The activities, however, of the Regional Transportation District, combined with the existing traffic operations activities of both the City Public Works Department and the Colorado Department of Highways provide an excellent base on which to develop an areawide, coordinated traffic systems program.

4) Preferential treatment opportunities that will contribute to large travel time differences between bus and auto are limited in Denver because of the already high levels of highway service, the relatively low densities

of trip origins and destinations, and the absence of extensive freeway and arterial congestion. Opportunities are, in most cases, limited to spot improvements (for example, ramp preferential treatment) or to improvements in overall flow conditions (for example, ramp metering).

5) Costs of implementing and administering preferential treatment facilities have not proven to be a barrier, amounting to $3,200 for the 16th-17th lanes, and $71,000 for the Broadway-Lincoln lanes. Initial implementation costs have been supported through EPA and RTD funding, with maintenance and operating support provided directly by the City.

6) The preferential treatment facilities implemented to date have resulted in meaningful modal shifts and VMT reductions within the areas affected where a travel time advantage is provided for transit, Table 6-10. Even these cases, though, have not produced significant differences in door-to-door travel times. Principal accomplishments, instead, have been increased transit reliability on the routes served, and a high visibility means of promoting individual energy conservation and air quality improvement actions.

7) Even though large increases in transit ridership have not occurred, the two preferential bus projects are felt by most Denver officials (and by ourselves) to be fairly successful. Early enforcement and operation problems, where they existed, have been overcome.

8) Preferential treatment facilities require close coordination with the more traditional traffic operations and engineering activities. The adequate consideration of numerous design details involving traffic signal timing, parking, bus stop locations, turning movements, enforcement, signing, and

TABLE 6-10

Summary of Preferential Bus Lane Projects

Impact	Facility		
	16th-17th		Broadway-Lincoln
Cost	$3,200		$71,000
Transit Ridership (average passenger load)	no change		+40%
Bus Travel Times	- 15-30%		- 7-14%
Auto Travel Times	- 2-30%		-2.7% +3.8%
Safety	-		uncertain
Traffic Diversion	yes		yes, measurable
Violations and Enforcement	self-enforcing		requires police visibility
	%	Annual	Annual
VMT	0%	0	-600,000
Fuel	-8%	-32,400 gals.	- 49,180 gals.
CO	-2.5%	-29,160 lbs.	- 192,000 lbs.
HC	-2.8%	- 2,196 lbs.	- 13,200 lbs.

maintenance is essential to success and requires considerable understanding and effort. Frequently, preferential treatment can be supportive of overall improved operating conditions, and need not be looked at as only a disincentive to the drive alone automobile. Neither the 16th-17th nor the Broadway-Lincoln facilities has resulted in a significant worsening of automobile travel times, and on the 16th-17th lanes, automobile as well as transit speeds have improved. This improvement in speed and overall flow conditions contributes to reduced CO and HC emissions in this section of nearly 3 percent and improved fuel economy of 8 percent.

9) The effective implementation of preferential treatment facilities requires more institutional coordination than any other measure examined, with possibly as many as nine local, regional, state and federal agencies having planning, design, review and approval responsibilities. To date, RTD has assumed principal leadership, and this in large part accounts for the almost exclusive bus orientation. The City of Denver, including both the Traffic Engineering Division of the Public Works Department and the Police Department, can be characterized as "reluctant participants." The City has a long and nationally recognized history of traffic engineering improvements focusing on vehicle flow improvements, and the shift to an orientation of movement of persons is not yet perceived as a high priority. Similarly, the primary orientation of the Police Department is to safety, not management of traffic facilities, and the uncertain safety impacts of the Broadway-Lincoln bus lanes have not helped to obtain increased police support.

10) The effect of the large number of agencies involved in preferential treatment projects is not only the delay caused by the additional coordination

and negotiation required, but also the opportunity provided to agencies - each having essentially a different mission - to simply delay in carrying out assigned responsibilities if a project is not consistent with their own priorities. The impact of these delays is to lessen a measure's effectiveness since it provides those not favoring the measure an opportunity to take advantage of noncompliance with a low risk of incurring a penalty. The probability of such delays is increased since in no case is preferential treatment considered a top level priority of the agencies involved.

11) The implementation of preferential treatment facilities has been expedited by the existence of EPA's promulgated transportation control plan. The initial RTD feasibility study in 1974 was developed largely in response to the TCP, and RTD has used the existence of air quality transportation controls as a mechanism to assist them in accomplishing projects that were otherwise compatible with their basic objective of improved transit.

REFERENCES

(1) Colorado Air Pollution Control Commission, The State of Colorado Air Pollution Control Transportation and Land Use Plan, Denver, Colorado, May, 1973.

(2) U.S. Environmental Protection Agency, "Approval and Promulgation of Implementation Plans, Colorado Transportation Control Plan," Title 40, Chapter 1, Subchapter C, Part 52, Federal Register, Vol. 38, No. 214, November 7, 1973.

(3) Colorado Air Pollution Control Commission, Regulation No. 9, "The Control of Automotive Air Pollution Through The Encouragement of Public Transportation and Motor Vehicle Restraints," July 25, 1974, as amended November 13, 1975.

(4) Gaudette, John J., Preferential Treatment for High Occupancy Vehicles in the Denver Metropolitan Area: A Feasibility Study, submitted to the Regional Transportation District, Denver, Colorado, June, 1974.

(5) Wilbur Smith and Associates, I-70/6th Avenue Bus and Carpool Study, prepared for Colorado Division of Highways, September, 1976.

(6) Alan M. Voorhees & Associates, Inc., Denver Bus and Carpool Lanes, Before and After Study, prepared for the City and County of Denver, February, 1975.

(7) Centennial Engineering, Inc, Before and After Evaluation, Exclusive Peak Hour Bus Lane Demonstration Program, Broadway and Lincoln Street, Denver, Colorado, prepared for the City and County of Denver, June, 1976.

(8) Cambridge Systematics, Inc. (with Alan M. Voorhees & Associates, Inc.), Carpool Incentives, Evaluation of Operational Experience, prepared for U.S. Federal Energy Administration (Springfield, Virginia: National Technical Information Service), PB 263 050-7WT, March, 1976.

(9) NATO Committee on the Challenges of Modern Society, Bus Priority Systems, CCMS Report No. 45 (United Kingdom: Transport and Road Research Laboratory, Department of the Environment), 1976.

CHAPTER 7

PARKING MANAGEMENT

PARKING MANAGEMENT AND THE DENVER TCP

Parking management can be described as the control of parking supply, location or rates in a manner which influences the amount of automobile parking in certain areas, during certain times of the day or for certain trip purposes. Frequently it is undertaken in conjunction with other measures to encourage transit use or other ride sharing by providing incentives or a convenient gathering or transfer point at a peripheral location. Parking measures can be regional in scope or they can be undertaken on a localized basis; for example, to minimize carbon monoxide hot spot problems. Thus, parking management really is an umbrella category for a variety of policies and actions which cover a broad spectrum from park and ride to parking supply freezes to price increases (Table 7-1). Potential impacts also can be very broad, affecting modal usage, trip destination, and the distribution of economic activity (Table 7-2). Parking controls typically are designed to be highly discretionary; for example, discouraging home-to-work commuting by single occupant auto while simultaneously promoting more shopping and other types of non-work trip making.

The EPA-promulgated transportation control plan contained provisions for two kinds of parking management (2):

1) parking lot construction limitation

2) limitation of on-street parking

The accompanying text observes:

TABLE 7-1

Example Parking Management Measures

- Elimination of on-street parking, especially during peak periods
- Favoring parking by short-term users over all-day commuters by:
  - placing a time limit on the duration of parking
  - prohibiting automobiles from parking prior to a certain hour
  - changing the price structure to favor short-term use
- Strict enforcement of parking regulations
- Regulation of the supply of parking spaces by:
  - depleting the existing inventory of parking spaces
  - freezing the number of parking spaces provided at the existing level
  - constraining increases in the supply of new parking spaces
  - establishing residential and other area license schemes
  - placing restrictions on the use of existing facilities
- Regulation of the rates at public and private parking facilities by:
  - parking tax
  - parking surcharge
  - parking price modification
  - parking rate structure revision
- Provision of fringe and transportation corridor parking to facilitate transfer to transit and other high occupancy vehicles by:
  - utilizing parking facilities constructed as part of other public or private projects
  - assuming investment and operating costs of such facilities by a public agency

TABLE 7-2

Possible Impacts of Parking Measures

Beneficial	Adverse[1]
- in conjunction with the mall and park and ride, creation of unique downtown environment with fewer cars	- losses to parking operators
- relatively small CBD, conducive to walking	- losses in retail sales
- differentiate from suburban shopping centers	- losses in revenues to city
- aesthetics	- administrative costs - DPW
- encourage use of transit and park and ride	- reduction in attractiveness of CBD
- decrease amount of time spent cruising for parking space	- increased costs to individual parker
- fewer autos downtown results in more pleasant environment for pedestrians and bicyclists	- because it ultimately will matter how much people are willing to pay, burden of shifting to other modes may fall most heavily on lower income individuals
- reduce the amount of congestion by reducing the number of cars driving on city streets during peak periods	- cost of increased enforcements of violation
- reduce the amount of carbon monoxide (CO) by reducing the number of vehicles and the amount of idling done by vehicles	
- reduce VMT	
- increases in revenue to city	
- decrease in accidents associated with curb parking (pulling out into lane of traffic without looking, hitting bicyclists with car doors, etc.)	

[1] Note that some impacts appear in both columns - actual impacts are a function of the details of operation of specific measures and the "success" of the measure in achieving desired travel changes.

SOURCE: (1)

> "The parking lot construction regulation...alone could have more than the effect of stopping new VMT growth because land now used for parking will be converted to other uses through urban renewal. The effect in the central business district of (the measure) will be much greater because this is where most of the conversion of parking lots to other uses will occur."

In addition, the text states:

> "...elimination of on-street parking in the core area will have little effect because there is very little of such parking now" (38 Federal Register 30820, November 7, 1973).

Regulation 9, which was issued in part to implement the promulgated transportation control plan, contains several provisions relevant to parking management (3):

- Development of a plan for automobile intercept parking facilities and express bus service to employment and business centers shall be done jointly by DRCOG, CDH, RTD and local business and employment center associations.
- Free and/or reserved employer-provided parking for carpool vehicles shall be implemented.
- A study is to be performed by DRCOG in cooperation with CDH and RTD on "...the relationship, if any, between restricting the construction of new parking spaces in the Denver area and reducing vehicle miles travelled. It shall also recommend to the commission parking requirements that may stimulate the use of public transportation and decrease single passenger vehicle miles travelled.

The transit park and ride program is well under way; three regional park and ride facilities are in place, another seven are planned, and approximately 50 smaller joint use sites scattered throughout the metropolitan area have been obtained. Also, a number of on-street spaces have been removed from the CBD to facilitate the flow of traffic and permit the implementation of exclusive transit lanes. However, construction of planned parking facilities in the CBD has continued as originally scheduled. In addition, DRCOG was reluctant to undertake the parking management study called for in Regulation 9 concerning restrictions on new parking construction. However, when federal certification of the urban transportation planning process was withheld in 1976, DRCOG finally agreed to undertake a parking study and such an effort will be completed during the Spring of 1978.

Since there are no significant parking management implementation results in Denver, the emphasis in this chapter is on general issues involved in designing a parking management program and on an assessment of the overall potential of parking management. Institutional as well as technical considerations are examined, providing considerable understanding of the reasons behind Denver's reluctant endorsement of parking management. The focus is on the central business district, consistent with the historical treatment of parking management concepts in transportation control plans.

Experience in other cities has demonstrated that very similar kinds of concerns to those raised in Denver arise when parking management is proposed. Specifically, the large number of agencies having responsibilities over various aspects of parking makes it difficult to achieve consensus on parking management plans and policies. Some aspects, such as the control of rates charged at commercial facilities, may not be the responsibility of any agency. Furthermore, a number of actors from the business community, as well as the public at large, generally have a stake in the parking changes. The high level of interest in parking can be attributed to a number of factors, most importantly the fact that parking management often is proposed only as a disincentive measure. Even when agreement on a plan of action has been achieved, the successful implementation of parking controls is dependent on reaching agreements among the various agencies with authority over parking. Furthermore, the implementation of some parking management measures, such as changing the rates or rate structure at commercial facilities, may require additional grants of authority, the acquisition of which may take a long time and require extensive negotiations.

There are, in addition, numerous concerns of a more technical nature. Because of the highly fragmented nature of parking supply - different ownership, facility types, rate structure, users served, duration of occupancy - a policy normally must be adaptable to the unique characteristics of different facilities. For example, supply constraints may be feasible in those areas where demand exceeds or is at least near existing parking supply. They will accomplish little, though, in those parts of a city where there already is a considerable excess of parking capacity.

PARKING CHARACTERISTICS IN THE DENVER CBD

The downtown area of Denver is supplied with ample parking at a modest cost, and access to the CBD by automobile is direct and relatively uncongested. As in most cities, ownership of parking facilities is both public and private in Denver, although the city owns relatively few spaces for a city of its size. While the TCP calls for parking limitations in the CBD, current construction and planned development will increase the total number of spaces in the downtown area.

Allocation of Responsibility

Several agencies in Denver have authority over and interests in parking; however, there is no single agency, such as a parking authority, with overall responsibility.[1] At present, no agency exercises control over the location, number of spaces, or price charged at any privately owned parking facility in Denver. In addition, the agencies differ in their sense of what role parking should play in Denver's transportation system.

The Department of Public Works (DPW) owns and controls municipal on- and off-street parking facilities.[2] In addition, DPW reviews proposed facilities to determine whether or not access and egress is adequate and issues permits for curb cuts. However, this review is not used as a means of limiting or otherwise restricting the number of parking spaces. Parking rates are not regulated, and attempts to date to narrow the scope of free enterprise have not been received favorably.

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[1] Formation of a parking authority was one of the recommendations of an early 16th Street mall study as it was seen as a means of implementing two policies: 1) elimination of surface parking lots between 15th and 17th Streets, and 2) modification of the parking rate structure at facilities between 15th and 17th Streets to assure an adequate supply of short-term parking spaces, and to discourage long-term parking.

[2] The Denver Urban Renewal Authority (DURA) also is a city operator of parking through its leases to parking companies of off-street open air lots on parcels which have been cleared for development but not yet sold.

The amount of parking space required for development in the downtown area is established by the Zoning Administration. In the downtown area, one parking space is required for each 600 square feet of gross floor area in the B-7 zone; in the B-5 zone which includes the CBD core, no parking is required (Figure 7-1). It is through the zoning requirement that most cities have been able to build up the supply of off-street parking. Despite the fact that the Denver TCP contains a provision for restricting additional spaces through changed zoning requirements (for example, by specifying a maximum allowable number of spaces rather than a minimum allowable), the Zoning Administration has been reluctant to modify its regulations to require fewer parking spaces or to change the required minimum to a required maximum unless there is evidence that people will use alternatives means of getting downtown. The Zoning Administration believes that until there are adequate transit alternatives, providing parking is important in maintaining accessibility to the CBD.

The Denver Planning Office, though charged with responsibility for planning the future of the City, can only make recommendations on what it feels should be done about parking in the City as part of its transportation planning component. It has no direct implementation or operating responsibility. In a recent report issued jointly by the Denver Planning Office and Downtown Denver, Inc., it is stated that:

> The arrangement of Downtown parking facilities should reinforce the core area and accommodate both short-and long-term needs with a minimum of intrusion into and disruption of adjacent neighborhoods (4).

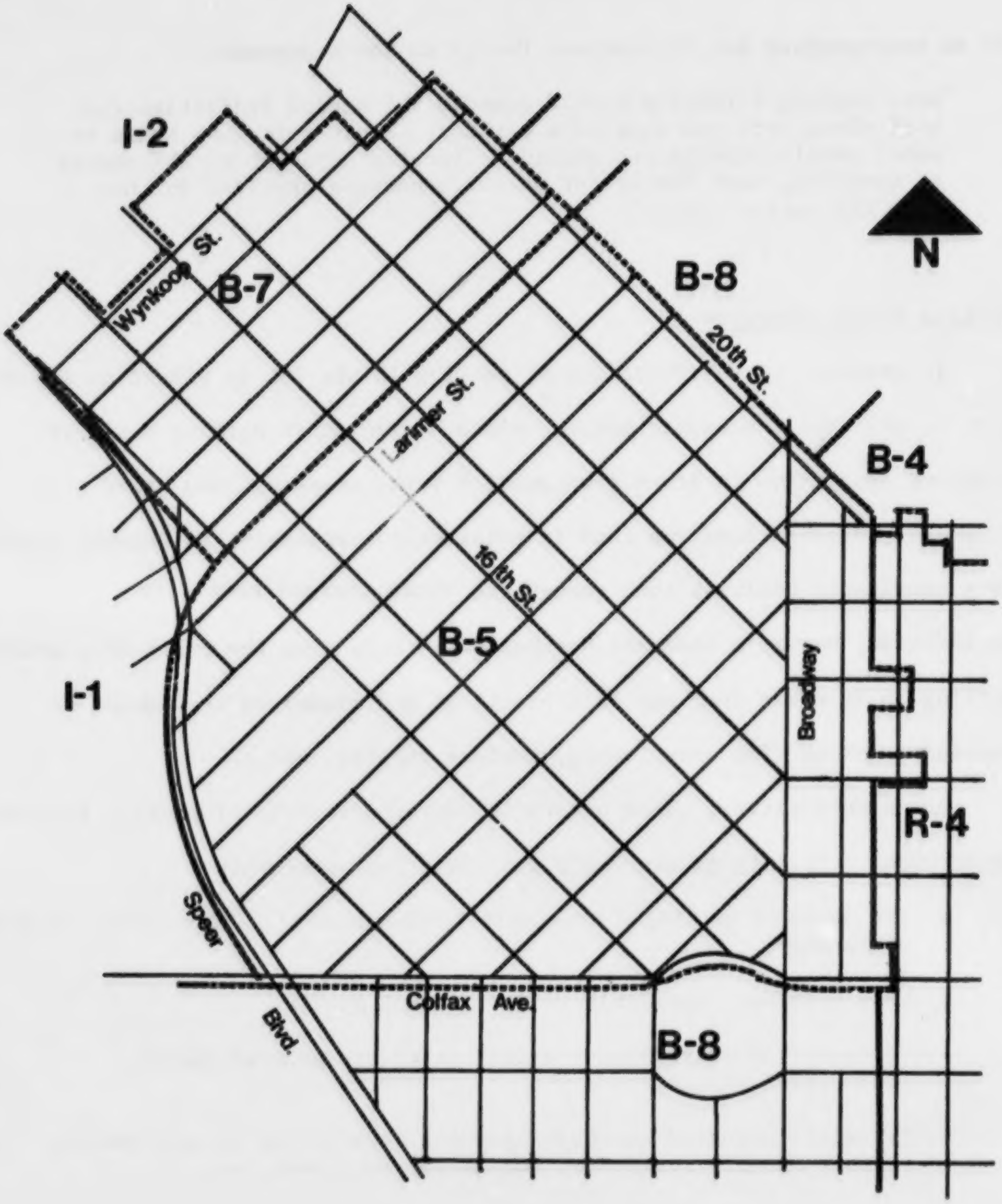
I-2
B-7
Wynkoop St.
B-8
N
20th St.
Larimer St.
B-4
16th St.
B-5
Broadway
I-1
R-4
Speer
Blvd.
Colfax Ave.
B-8

FIGURE 7-1

Existing Zonal Parking Requirements

On an accompanying map of Downtown Denver is the statement:

> "Auto Parking Terminals should provide the needed facilities for both short-term and long-term parking. Short-term (two hours or less) parking facilities should be located adjacent to the center of Downtown, with the longer duration parking provided further from the center" (4).

Parking Supply Overview

In general, the availability of parking in the CBD is viewed as important to the area's economic health, since having ample parking makes it easy and attractive to drive downtown for work, shopping, and other trip purposes. Because downtown land is relatively inexpensive in Denver, parking is a profitable business even though the rates charged seemed low. In addition, Denver's moderate weather helps keep down the costs of providing parking as it makes open air lots practical and minimizes the amount of necessary upkeep (for snowplowing, surface repairs, etc.).

As in most cities, there exists in Denver a variety of parking facility types under a variety of ownership and operation agreements:

- DPW managed parking - available to the general public (both on- and off-street)
- DURA parking - available to the general public
- Privately-owned parking - available to the general public (commercial parking)
- Private or limited-use parking - not open to the general public or only open to residents, customers, employees, etc.

A 1976 inventory of off-street parking facilities shows a total of 31,693 off-street parking spaces in the area inside the dashed line on Figure 7-2 (5). Approximately 75 percent of these spaces were available to the general public, 21.000 of which were in DURA and privately-owned

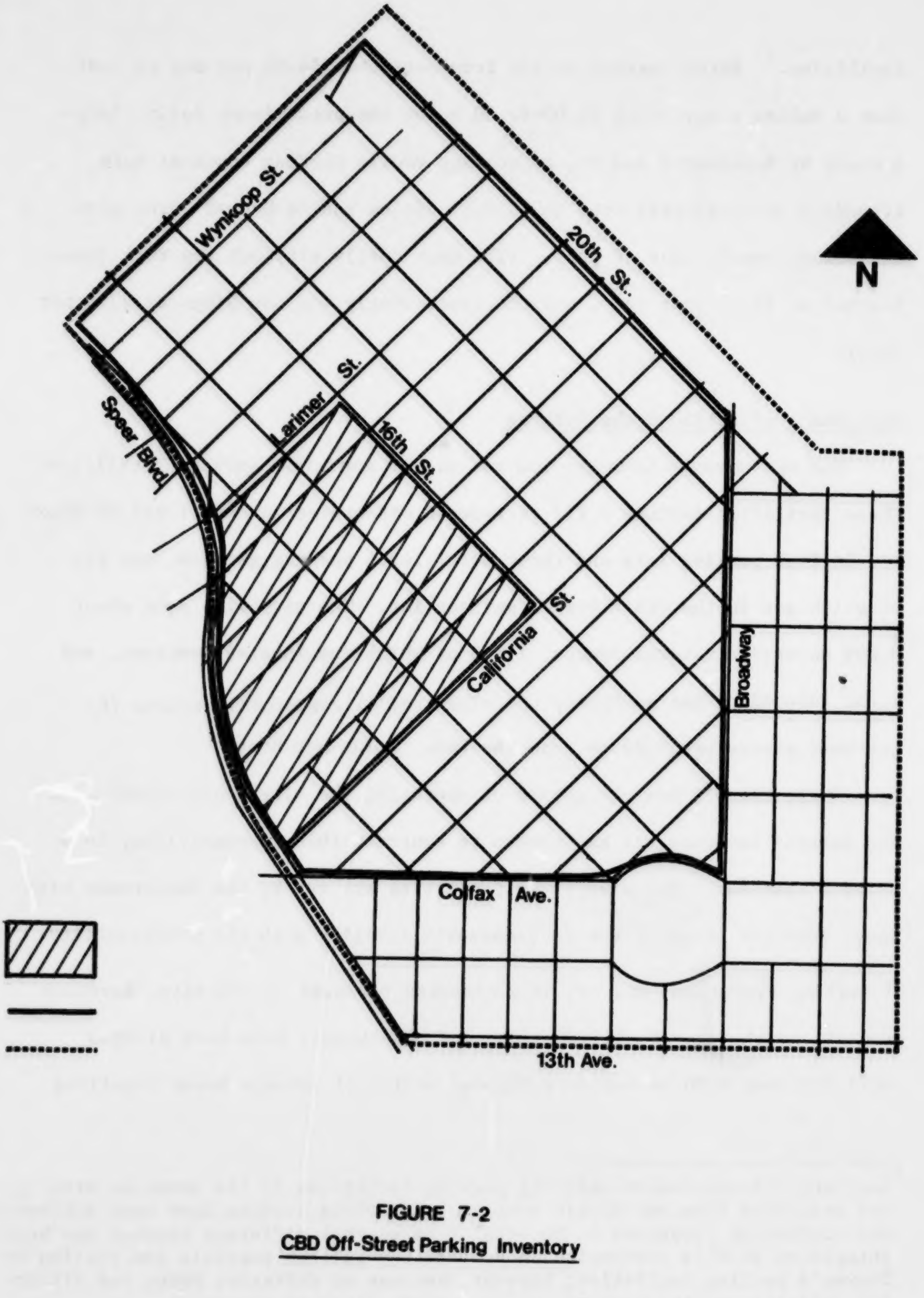
Wynkoop St.
20th St.
N
Larimer St.
16th St.
Speer Blvd.
California St.
Broadway
Colfax Ave.
13th Ave.

FIGURE 7-2

CBD Off-Street Parking Inventory

facilities.[1] Rates charged varied from more than $4.00 per day to less than a dollar a day, with $1.00-$2.00 being the predominant daily charge. A study by Runzheimer and Co. of average yearly parking costs at both attendant and self-park lots in 50 U.S. cities ranked Denver 26th, with an average yearly cost of $325. (The most costly city was New York (Manhattan) at $1,127 per year, and the least costly was San Diego at $258 per year.)

Department of Public Works Parking

The DPW manages both on- and off-street municipal parking facilities. These facilities include 2,151 city-owned off-street spaces, 1,913 of which are in four parking lots and three multi-level parking garages, and 238 of which are in the Court Street surface lot. The city also owns about 3,000 on-street metered spaces, 1,140 of which are located downtown, and 1,850 located on the periphery and along radial commercial streets (6). One hour meters predominate, and the rate is 20¢ per hour.

While the DPW has the option of operating the city's off-street lots and garages in-house, it has chosen to contract this responsibility to a private operator. Rates at these facilities are set by the Department with input from the operator who is presumably familiar with the profitability of parking operations and can help maximize revenues to the city. Revenues from all of the city facilities (on- and off-street) have been pledged until the year 2000 as security for two series of revenue bonds totalling

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[1] Complete information on existing parking facilities in the downtown area is not available from any single source, and various studies have used different definitions of "downtown." Material from several different sources has been integrated in this discussion to provide the fullest possible description of Denver's parking facilities; however, because of differing dates and differing definitions, the numbers are not always directly compatible.

$18,000,000 for the construction of two recent new parking facilities, a 1,788 space garage for the Denver Convention Center and Center for the Performing Arts, and a 1,120 space garage for the Denver General Hospital. (Major improvements to existing surface lots will add another 430 parking spaces in the vicinity of the hospital.) Rates for the Performing Arts facility are shown in Table 7-3, with a summary of recent annual parking revenues for other city facilities shown in Table 7-4. In accordance with the bond ordinances, revenues from existing facilities and the new facilities will be put into a special fund to pay off the city's bond debt. If the revenues exceed the amount required to meet bonding obligations, the excess revenue will go into the city's general fund.

The number of on-street parking facilities in the downtown area was reduced from 3,168 to 2,990 spaces between 1970 and 1976. The primary motivation for removal of these spaces was to improve traffic flow on downtown streets.[1] In addition, the hourly rate for parking meters was doubled by a City Council Ordinance on October 27, 1975, from 10¢ to 20¢. This rate increase was passed just before the bond issue for the new parking facilities and was motivated by a desire to increase parking revenues to the city.

The city has a long-range plan of selling its small mechanical garages and eventually hopes to have all of its spaces in a few large facilities. For example, in December, 1976, the city sold the 380-space mechanical parking garage located on Tremont Street for a net gain of $169,685. The proceeds from the sale amount to $750,000 and will be used for bond retirement as

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[1] Enforcement of parking regulations by the Denver Police Department yielded in 1976 an estimated $1,539,390 to the city's general fund.

TABLE 7-3

Proposed Rates at Denver Center for Performing Arts Garage

Time Period	Proposed Parking Charges	
	Introduction Rate	Rate after 6/1/78
1. Weekday		
a. Base Charge	$ 0.25/hour	$ 0.25/½ hour
b. All day to 6 PM	$ 2.50	$ 3.00
c. All day (including overnight)	$ 3.50	$ 4.00
d. Evenings	$ 1.00	$ 1.00
2. Saturday		
a. Base Charge	$ 0.25/hour	$ 0.25/½ hour
b. All day to 6 PM	$ 2.00	$ 2.00
c. After 6 PM	$ 1.00	$ 1.00
3. Monthly Rate	$30.00	$30.00

TABLE 7-4

DPW Parking Revenues

Year	On-Street Parking Meters	Court Place Lot	1952 Off-Street Parking Facilities(1)	Total Pledged Revenue
1971	$398,386	$ 2,765	$270,705	$671,856
1972	380,272	141,181	218,920	740,373
1973	339,027	141,181	282,694	762,902
1974	326,135	138,780	381,166(2)	846,081
1975	339,457	138,780	89,393(3)	567,630

SOURCE: (6)

(1) Net income for the 1952 Off-Street Parking Facilities is revenue to the City, less elevator maintenance costs, but excluding debt service on 1952 bonds.

(2) Revenue for 1974 was for a 15-month period from October 1, 1973, to December 31, 1974, caused by conversion to a "calendar year" fiscal year.

(3) Because of a change in operator contracts, a one-month shutdown of all garages, and extraordinary costs for garage elevator overhaul, 1975 revenue is greatly reduced. The figure shown is net income and does not include cost for elevator overhaul.

required by the bond ordinances (7).

Because of the pledged revenue situation and the general orientation of the Traffic Engineering Division toward improving automobile access and facilitating traffic flow, the DPW does not feel that it can pursue parking management proposals which involve altering rate schemes or changing the parking supply (either on- or off-street).

Urban Renewal Authority Parking

The Urban Renewal Authority has established open-air parking lots on parcels in the urban renewal area which have been cleared for development but have not been sold. Operation of the lots has been contracted to a private operator who returns approximately $65,000 per month to the DURA; revenues are used for current operation of the Authority. In an assessment of Denver's parking supply prepared as part of the parking bond issue, it was stated:

> "Parking rates have been kept at an unrealistically low level for several years because of the abundance of several blocks of temporary surface parking in the Skyline and Aurania Urban Renewal Areas. These spaces have created parking surpluses leading to low costs for long-term and all-day parkers" (6).

The Urban Renewal Authority has 13 parking lots as of January, 1978. The daily rate was $0.75 at one of the facilities, $1.00 at three facilities, $1.50 at seven facilities, and at the remaining two facilities, the monthly rate was $14.00 (Figure 7-3). As shown in Figure 7-4 relating DURA lots to other facilities located in the vicinity of the Center for Performing Arts[1], although the DURA lot rates are low, non-DURA lot rates in the immediate vicinity of the urban renewal area also are low, in some cases lower than the rate at the nearby DURA lot.

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[1] This area corresponds to the cross-hatched area in Figure 7-2.

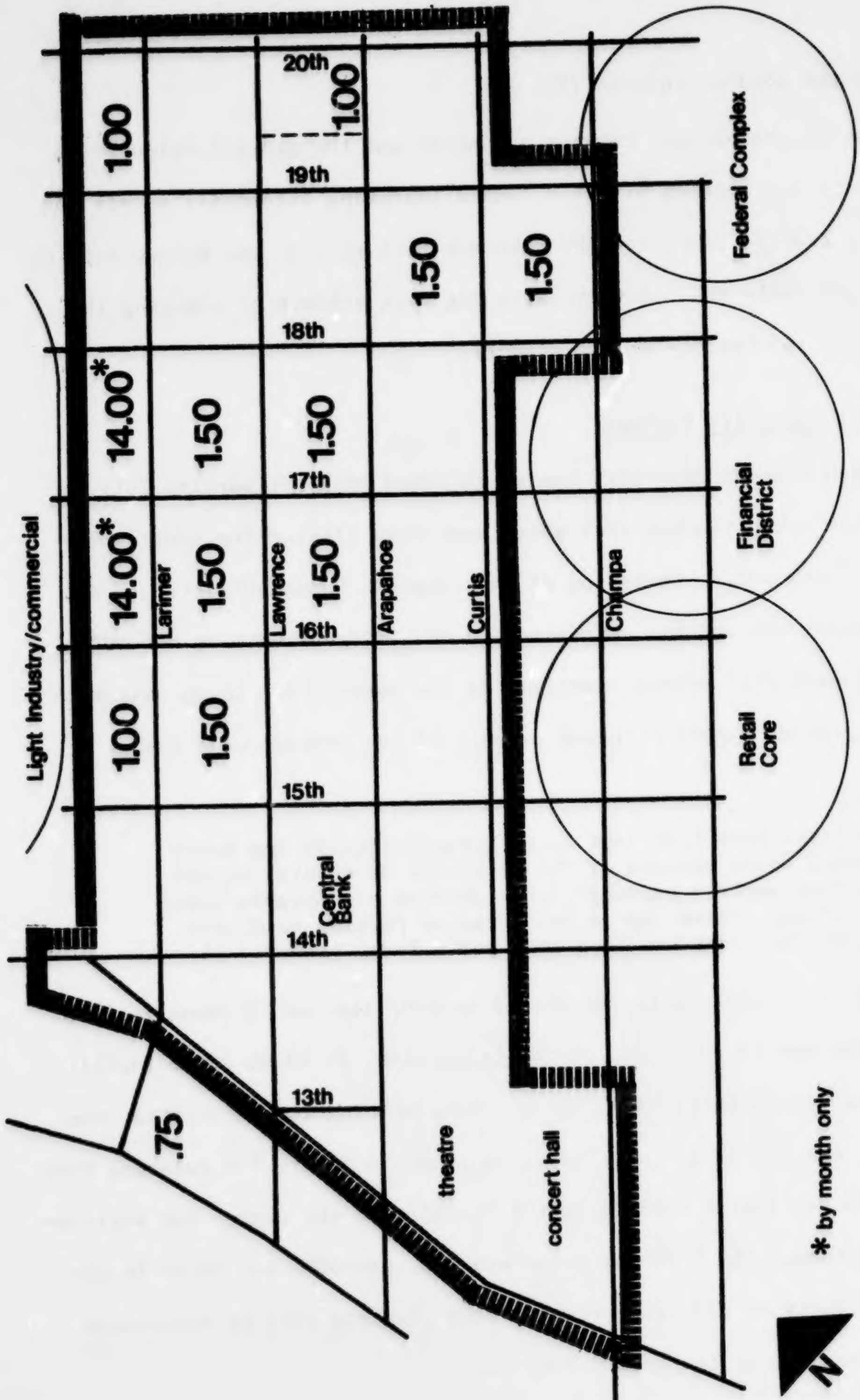
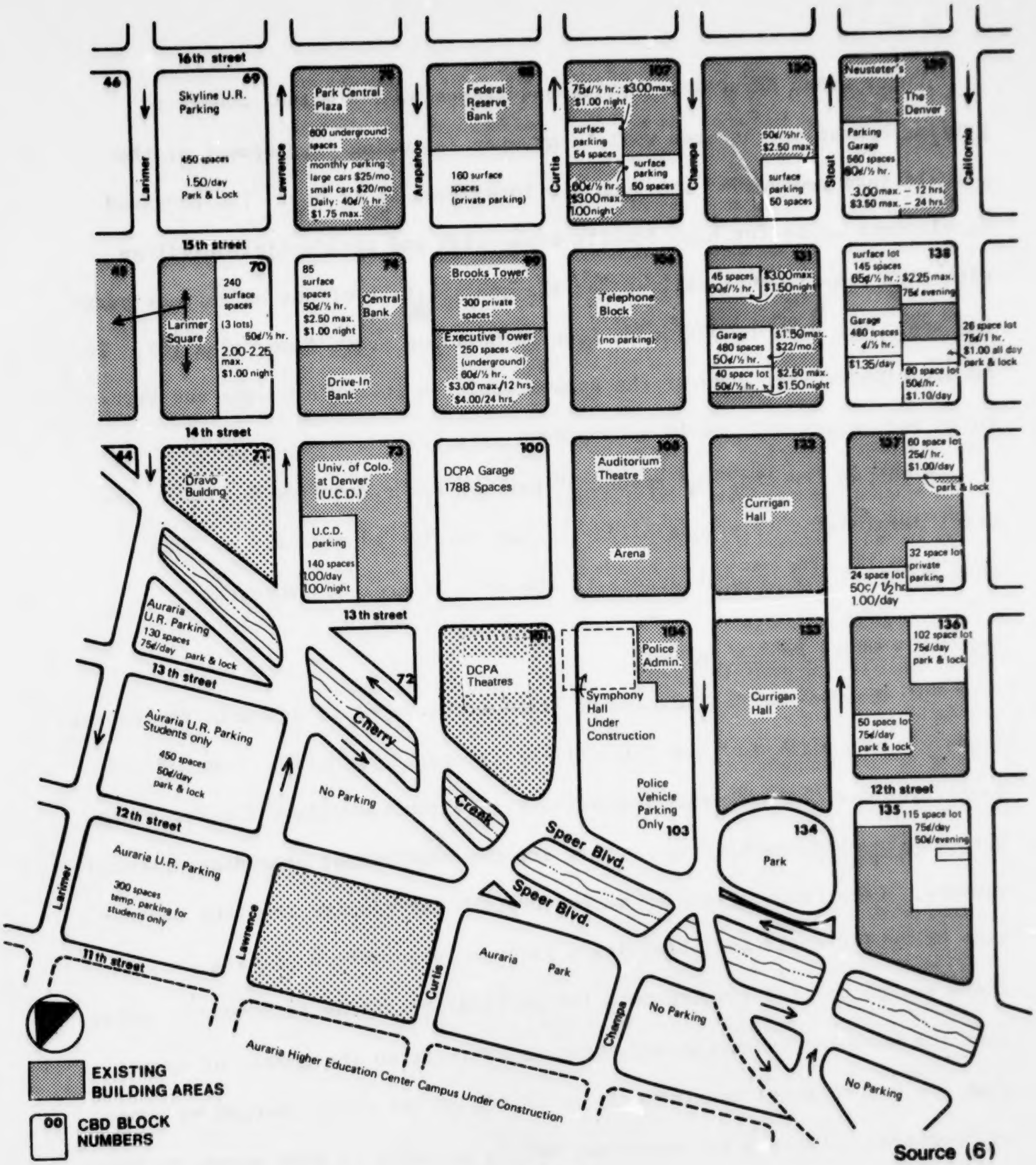

Light Industry/commercial
20th
19th
18th
17th
16th
15th
14th
13th
Larimer
Lawrence
Arapahoe
Curtis
Champa
1.00
1.00
1.50
1.50
14.00*
14.00*
1.50
1.50
1.50
1.50
1.00
1.50
Central Bank
.75
theatre
concert hall
Federal Complex
Financial District
Retail Core
* by month only
N

FIGURE 7-3

Location of Urban Renewal Authority Parking Lots and Current Charges


16th street
15th street
14th street
13th street
12th street
11th street
Larimer
Lawrence
Arapahoe
Curtis
Champa
Stout
California
46
69 Skyline U.R. Parking
450 spaces
1.50/day
Park & Lock
76 Park Central Plaza
800 underground spaces
monthly parking: large cars $25/mo. small cars $20/mo.
Daily: 40¢/½ hr. $1.75 max.
Federal Reserve Bank
160 surface spaces (private parking)
107
75¢/½ hr.; $3.00 max. $1.00 night
surface parking 54 spaces
surface parking 50 spaces
60¢/½ hr. $3.00 max. 1.00 night
130
50¢/½ hr. $2.50 max.
surface parking 50 spaces
Neusteter's
The Denver
Parking Garage 560 spaces 60¢/½ hr.
3.00 max. – 12 hrs. $3.50 max. – 24 hrs.
70
Larimer Square
240 surface spaces (3 lots)
50¢/½ hr.
2.00-2.25 max.
$1.00 night
85 surface spaces
50¢/½ hr.
$2.50 max.
$1.00 night
Central Bank
Drive-In Bank
Brooks Tower
300 private spaces
Executive Tower
250 spaces (underground)
60¢/½ hr., $3.00 max./12 hrs. $4.00/24 hrs.
Telephone Block
(no parking)
131
45 spaces 60¢/½ hr.
$3.00 max. $1.50 night
Garage 480 spaces 50¢/½ hr.
$1.50 max. $22/mo.
40 space lot 50¢/½ hr.
$2.50 max. $1.50 night
138
surface lot 145 spaces
65¢/½ hr.; $2.25 max.
75¢ evening
Garage 480 spaces ¢/½ hr.
$1.35/day
26 space lot 75¢/1 hr. $1.00 all day park & lock
60 space lot 50¢/hr. $1.10/day
44
71 Dravo Building
73 Univ. of Colo. at Denver (U.C.D.)
U.C.D. parking 140 spaces 1.00/day 1.00/night
100 DCPA Garage 1788 Spaces
Auditorium Theatre
Arena
132 Currigan Hall
137
60 space lot 25¢/hr. $1.00/day park & lock
32 space lot private parking
24 space lot 50¢/½ hr 1.00/day
Auraria U.R. Parking 130 spaces 75¢/day park & lock
72
101 DCPA Theatres
104 Police Admin.
Symphony Hall Under Construction
Police Vehicle Parking Only 103
133 Currigan Hall
136 102 space lot 75¢/day park & lock
50 space lot 75¢/day park & lock
Cherry
Creek
Auraria U.R. Parking Students only
450 spaces 50¢/day park & lock
No Parking
Speer Blvd.
Speer Blvd.
135 115 space lot 75¢/day 50¢/evening
134 Park
Auraria U.R. Parking
300 spaces temp. parking for students only
Auraria Park
No Parking
No Parking
Auraria Higher Education Center Campus Under Construction
▨ EXISTING BUILDING AREAS
00 CBD BLOCK NUMBERS

Source (6)

FIGURE 7-4

Locations and Rates at Parking Facilities

Dec. 1977

Under Urban Renewal Authority requirements, the actual number of parking spaces in the area will be greater following development of the parcels (and removal of the open air lots) than it is now. The proposed development calls for high density commercial and residential buildings, with DURA requirements calling for the construction of one off-street parking space for each 1,000 square feet of building gross floor area (8). It is anticipated that some of the spaces would be in surface lots and structures and others will be in underground garages.

Although reducing the amount of parking space required for urban renewal development is a possibility, it is considered unlikely by DURA leadership unless transit access to the area is greatly improved.

Privately-Owned Public Parking

Privately-owned public parking (commercial parking) accounts for approximately 50-70 percent of the CBD's off-street parking supply. Some of the facilities are the park-and-lock variety in which the driver inserts coins into a meter-like machine and others are the traditional attendant-operated variety. Other than obtaining necessary curb cut permits from the Department of Public Works and obtaining a license to operate a parking lot, there are no special requirements for parking operations in Denver[1]. Entry into the business is unlimited; there is no limit on the number of spaces that one may operate; and there is no review of the rates charged by owners or operators. Parking lot operators are in business to make money, so proposals to regulate the industry have been viewed with skepticism.

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[1] The average annual cost of a parking license is about $100. In 1977, about 300 licensed lots in the City produced $29,000 in license fees.

In addition to the fact that the costs of operating parking facilities in Denver are relatively low due to the moderate weather, open air parking lots are taxed as though they are unimproved land, resulting in a very favorable rate to the owner. This tax advantage often prompts the establishment of parking lots as an interim use, as in DURA's case, so that the developer can receive revenue from the property prior to building construction. From the City's point of view, this practice is undesirable in the sense that demolishing structures reduces the amount of taxable income that the City receives from the parcel. There are no special taxes on parking operations in Denver other than the annual license fee.

Privately-Owned Private Parking

Private or limited-use parking - that is, parking which is open only to customers, clients, residents, or employees - constitutes 15-25 percent of the downtown parking supply. A 1976 examination of the area bounded by W. Colfax Avenue, Broadway, 20th Street, the railroad tracks and Speer Boulevard (the area inside the solid line on Figure 7-2) shows that of a total of 21,814 spaces, 16,745 or 77 percent were available to the public, and 5,069 or 23 percent were private. Of the private spaces, 46 percent were contained in parking garages, and the remaining 54 percent were in off-street lots.[1]

Included in the private or limited-use category are businesses and institutions who own or lease parking space for use by employees and customers, typically making the spaces available free or at a nominal charge. When asked to consider reducing the amount of parking made available or charging employees for the full cost of the parking space, employers are often reluctant and observe that parking availability is considered to be a fringe benefit to employees, and any change in its availability would cause employees to feel they had lost something and expect some other form of compensation. Retail and other commercial operations which provide parking space to customers are generally reluctant to decrease the amount of space available or establish a parking charge because they feel that such measures will drive customers away. This argument is used particularly by retail merchants in the downtown area who fear the CBD parking controls will simply enhance the attractiveness of suburban shopping centers.

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[1] The data (May, 1976) shows that the private garage spaces are contained in seven locations, ranging in size from 18 spaces to 750 spaces, whereas the private lot spaces are contained in 55 locations, ranging in size from 6 to 166 spaces.

Parking Utilization

Work trip parkers represent the largest category of parking use. Of the cars parked in the Denver CBD during an average work day, 45 percent were for work trips, with the next largest category of trip purpose being personal business, which accounts for 7,960 or 15.9 percent of the cars parked (Table 7-5). During the period of peak accumulation, nearly 75 percent of the vehicles are those of workers. These cars generally arrive in the CBD early in the day and remain parked for six to nine hours. Many workers arrive in the CBD before retail and commercial establishments are open for business, so where commuters and shoppers are in competition for the same parking spaces, the commuters arrive earlier and have first chance at the lowest priced, most conveniently located spaces. Trips made for shopping, personal business, and several of the other categories listed in Table 7-5 are typically shorter in duration than work trips so the walk from parking facility to destination constitutes a relatively greater component of these short trips.

TABLE 7-5

Trip Purposes of Parkers with Center City Destinations, Average Weekday
January, 1970

Trip Purpose	10:00 AM - 6:00 PM		Peak Accumulation[1]	
	Number of Parked Vehicles	Percent of Total	Number of Parked Vehicles	Percent of Total
Home	327	.7	18,000	74.4
Work	22,725	45.4	200	.8
Commercial Business	3,666	7.3	1,000	4.1
Personal Business	7,960	15.9	1,400	5.8
Sales/Service	308	.6	50	.2
Shopping	5,929	11.8	1,500	6.2
Social/Recreational	2,032	4.1	300	1.2
Eat/Drink	726	1.5	200	.8
Loading/Unloading	1,360	2.7	350	1.4
School (estimate)	3,020	6.0	600	2.5
Other	2,021	4.0	600	2.5
TOTAL	50,074	100.0	24,200	99.9[2]

SOURCE: (9)

[1] Maximum parking accumulation occurred between 1:00 PM and 2:00 PM on the survey day.

[2] Less than 100 per cent because of rounding.

In examining the parking system in an area such as the Denver CBD, the two basic issues are whether or not there are a sufficient number of spaces available during the period of peak demand, and whether the spaces are located within a reasonable distance of the traveller's destination. During the peak demand for parking (maximum parking accumulation) occurring between 1:00 PM and 2:00 PM, about 85 percent of available capacity was utilized (9). Because this is an overall figure, it may include instances where there are a few vacant spaces scattered in several parking garages, as well as spaces which are not convenient to many downtown destinations, so that the "effective" vacancy rate in the CBD was actually lower than the 15 percent. However, there were a sufficient number of spaces in the CBD in 1970 to meet the peak period demand.

Addressing the second issue, whether or not the spaces are located within a reasonable distance of traveller destinations, requires an assessment of such factors as destination, parking duration, and walk time.

During the period of peak accumulation, 74.4 percent of parking was for work trips, and the next two largest categories of trip purpose were shopping (6.2 percent) and personal business (5.8 percent), (Table 7-5). Further, 74 percent of parkers at the time of maximum accumulation were accommodated in public off-street facilities, and 11 percent were accommodated in on-street spaces (Table 7-6). All facilities were at 80-86 percent capacity. Because on-street spaces generally have one-hour meters, and work trips tend to be associated with the longest term use, it is assumed that commuters do not park on-street. Because of the long duration of work trips, a parking space occupied by a commuter typically serves only one parker per day. With approximately 75 percent of the CBD parking spaces devoted to work trips, that leaves approximately 5,214 public off-street and 3,168 on-street spaces, or a total of 8,382 public spaces to serve all of the CBD non-work trip purposes. In addition, some of the private spaces will be available for some non-work trips, but the number of such spaces is not known. It is estimated that not more than half, or 2,300, of the private spaces would be available for non-work short-term trips.

TABLE 7-6

Peak Accumulation - Capacity by Facility Type

Facility Type	% of Capacity	Number	% of Total
Private Off-Street	79.9	3,680	15%
Public Off Street	85.8	17,898	74%
Curb	82.9	2,625	11%
Total	84.5	24,203	100%

SOURCE: (9)

Comparing the location of trip destinations in the CBD to the amount of parking available in those locations gives an indication of the competition for parking spaces in the CBD. As shown in Figure 7-5, 16th Street from Cleveland to Curtis forms the spine of an area containing the largest number of shopper destinations as well as a concentration of work trip locations. The ten zones with the highest volume of work trip destinations contain 67 percent of all work trip destinations, 70 percent of personal business trip destinations and 80 percent of CBD shopping destinations.[1]

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[1] Zone or area definitions are those used in the 1970 CBD parking survey.

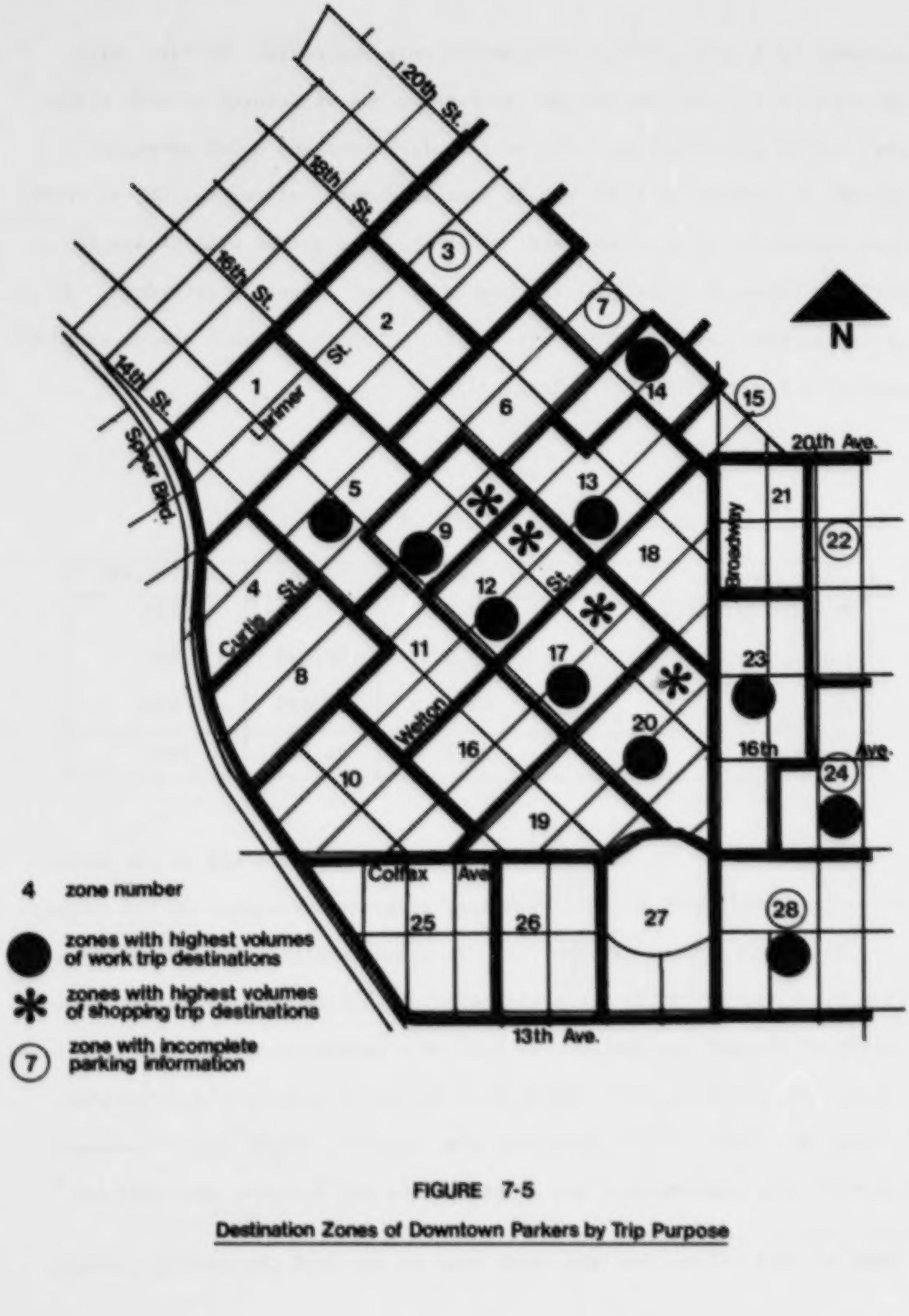
20th St.
18th St.
16th St.
14th St.
Larimer St.
Speer Blvd.
Curtis St.
Welton
Broadway
20th Ave.
16th Ave.
Colfax Ave.
13th Ave.
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
4 zone number
● zones with highest volumes of work trip destinations
✱ zones with highest volumes of shopping trip destinations
⑦ zone with incomplete parking information

FIGURE 7-5

Destination Zones of Downtown Parkers by Trip Purpose

In 1977, these 10 zones contained 10,051 off-street parking spaces, or approximately 1/3 of the total off-street CBD parking supply. The fact that areas of high work trip destination surround and coincide with the area of high shopping trip destinations simply exacerbates a situation which is already disadvantageous to shoppers because of their late arrival time and also because of the relatively small number of on-street spaces. Because of the need for parking facilities to be located within reasonable walking distance of the destination, the space availability versus trip destination picture changes rapidly as distance from the 16th Street spine increases. To give an idea of "reasonable" walking distance, the 1970 parking survey found that 76 percent of the parkers destined for Zones 5, 9, 12, 13, 14, 17, 20 and 23 walked less than 900 feet, with a walking time of about five minutes. Although the data do not show trip purposes for these parkers, it is likely that the majority are commuters. Zones 1, 2, 4, 8 and 10 on the edge of the CBD were examined on the assumption that the parking situation was quite different from that in the 16th Street spine. Although these zones contain only 12 percent of the total CBD trip destinations, they contain about 20 percent of the total CBD parking supply. In contrast, the 10 zones discussed previously contain 61 percent of the total CBD trip destinations and approximately 33 percent of the total parking supply. These data indicate that the zones at the edge of the CBD have considerably less competition for spaces, and vacancies in these zones probably bring down the average CBD occupancy rates discussed previously.

In summary;

- In 1970, there were sufficient total CBD parking spaces to meet demand at the time of maximum parking accumulation.
- Approximately 75 percent of the parking in the CBD is occupied by commuters who typically arrive early and remain parked throughout the day.

- The zones containing the largest number of shopping trip destinations overlap with and are surrounded by the zones containing the largest number of work trip destinations.
- Because of the timing and duration of commute trips, people making shopping and other short-term trips will always be at a disadvantage when the two must compete for the same scarce spaces.
- Zones on the edge of the CBD contain relatively few trip destinations compared to the amount of parking located in them.
- The differential in parking rates at facilities located in close proximity to one another encourages "cruising" for the lowest cost facility and generates excess VMT.

TRANSIT PARK AND RIDE

The development of a parking management program should focus neither on a single area nor on disincentives. To be successful, both a regional perspective and incentives are necessary. If changes are to occur in the amount or nature of parking utilization, it is necessary to provide alternative travel possibilities in order to maintain overall levels of trip making and accessibility. RTD's introduction of a system of regional park and ride lots provides an example of one such incentive with potential long-run impacts on parking downtown.

The concept of park and ride is simply that a commuter will drive to a suburban parking lot, park, and be picked up by a bus and taken downtown, thus avoiding the need to park downtown. RTD envisions a system of 10 regional park and ride facilities located a minimum of eight miles from the CBD, with high quality bus service between the park and ride lots and the downtown area. These lots will have a capacity of 500 cars each, and will be located as shown in Figure 7-6. At present, three of these lots are in use, and the remainder are programmed for construction within the next four years. Construction costs, including land acquisition, are running about one and one-half million dollars per facility, in part because of the need to site the facilities in high visibility, prime real estate locations. Operating and maintenance costs have proven to be minimal, with no new effort needed for either enforcement or day-to-day operation. Vandalism, to date, has not been a problem.

In addition to the regional park and ride facilities, RTD has encouraged churches and shopping centers to make parking spaces available to commuters in an effort to increase the desirability of making the final portion of the

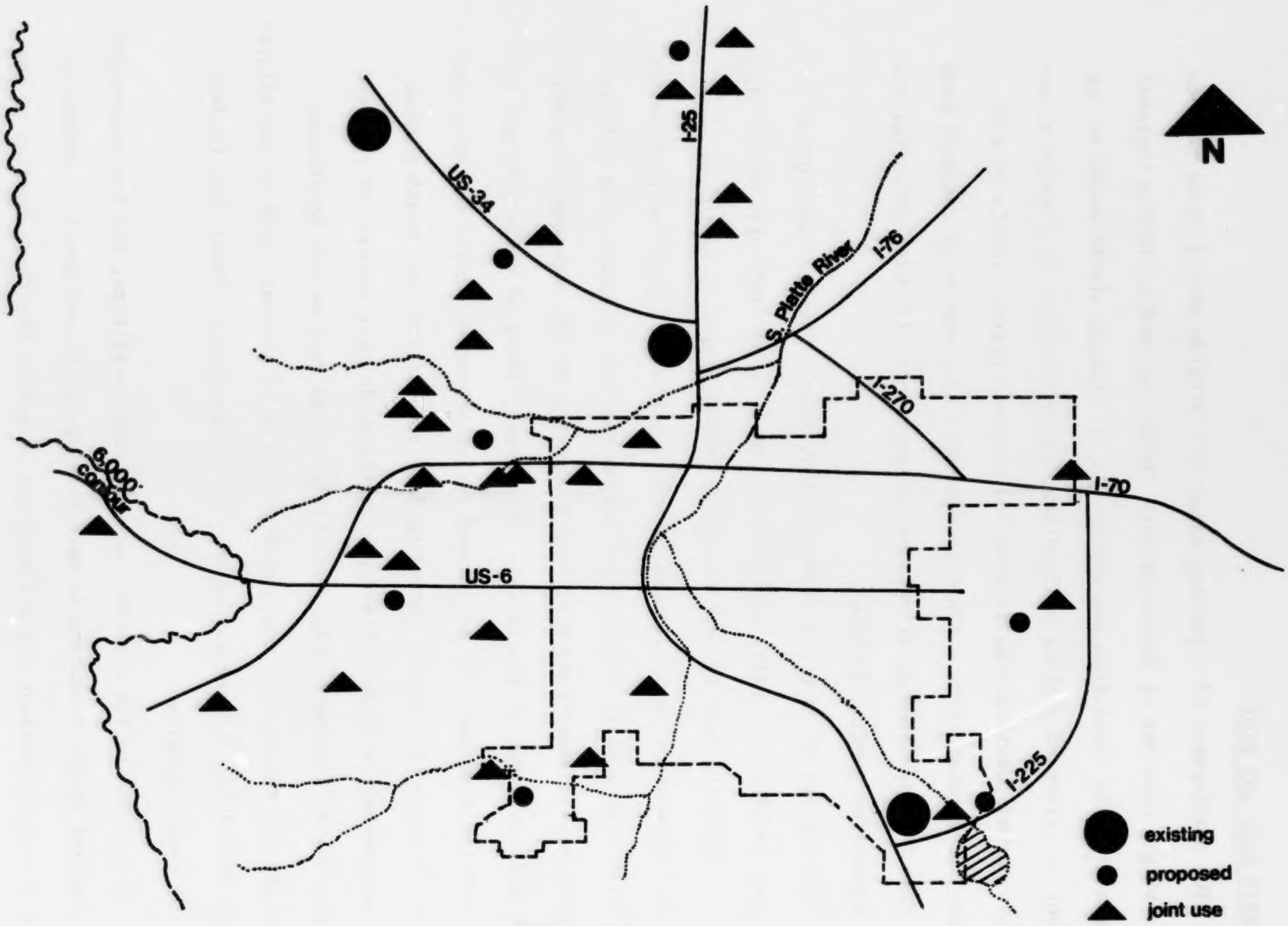
N
US-34
I-25
S. Platte River
I-76
I-270
I-70
US-6
6,000' contour
I-225
existing
proposed
joint use

FIGURE 7-6

Regional Park-N-Ride Sites

Source (10)

trip downtown by transit. These joint-use lots range in capacity from 10 to 150 spaces, and RTD has made more than 50 such arrangements, giving them a total of more than 10,000 planned park and ride spaces. The stability of some of these arrangements is an issue, and more formalized agreements with shopping centers are being sought. RTD will provide minor capital improvements (e.g. signs and shelters) in return for a five-year commitment that a certain number of spaces will be available for transit patrons.

Only very limited information on the total number of transit park and ride users is available. A survey conducted in July, 1975, at five joint-use park and ride facilities located in shopping centers indicated that 50 percent of the commuters surveyed live within a four-mile radius of the joint-use facility, and 71 percent of users drove their cars to the facility (10). Of importance to RTD, the results indicate that joint-use is advantageous to the shopping centers which provided spaces (10):

- 23 percent of joint-use riders began shopping at the centers surveyed after they started parking and riding the bus from the center
- 52 percent of joint-use riders parking at shopping centers started shopping more frequently at the center where they caught the bus.

VMT REDUCTION

An important question is the ability of various types and levels of parking controls to contribute to reduced vehicular emissions. This section focuses on determining possible VMT impacts of six example parking strategies. It is an assessment of the contribution of parking controls by themselves to air quality objectives and does not take into account the synergistic impacts of combining parking controls with improved transit, for example. In particular, the set of disaggregate travel demand models described in Appendix C was used to assess short-term impacts of increased parking costs and reductions in readily available parking supply (simulated by increasing out-of-vehicle walk time for both driving alone and shared ride).

The results of six candidate parking management measures are presented in Tables 7-7 and 7-8, four directed exclusively at CBD work trips and two impacting work trips on an areawide basis. To facilitate comparison, CBD work trip oriented VMT accounts for 11 percent of total areawide work related travel.

In summary, the options examined are forecast to result in modest, though meaningful, reductions in vehicle miles of travel within the target areas affected. For example, an increase of $1.00 in all CBD parking costs results in a 1.6 percent decrease in CBD work VMT, equivalent to an areawide decrease of approximately .2 percent. This $1.00 increase in cost for the private auto increases CBD transit ridership by 5.9 percent, and also induces a 3.6 percent increase in CBD ridesharing.

Since most work trip parking outside the CBD is both free and employer provided, a $1.00 per day areawide increase in the cost of commuter parking

TABLE 7-7

Example - CBD Oriented Parking Management Measures

% Change from Base (CBD Work Trips)

	WORK TRIP MODE SPLIT				Work Trip VMT (Miles/Day)	Work Trip Fuel Cons. (Gal/Day)	WORK TRIP AUTO EMISSIONS (Kg/DAY)		
	DRIVE ALONE	SHARED RIDE	TRANSIT	VANPOOL			HC	CO	NO_X
BASE (AVG/TRIP)	0.60	0.27	0.13	-	11.83	1.01	0.12	1.73	0.04
POLICY									
Increase CBD Park Cost (All Vehicles)									
+$1.00	-2.9	3.6	5.9	-	-1.6	-1.6	-1.7	-1.6	-1.6
+$2.00	-5.9	7.3	11.9	-	-3.3	-3.3	-3.4	-3.3	-3.3
Decrease CBD Parking Availability, Round Trip Walk Time									
+ 5 min.	-1.1	-2.0	8.7	-	-1.0	-1.1	-1.0	-1.1	-0.9
+10 min.	-2.3	-4.1	18.1	-	-2.1	-2.2	-2.2	-2.3	-2.0

TABLE 7-8

Example - Areawide Parking Management Measures

% Change from Base

	WORK TRIP MODE SPLIT				Work Trip VMT (Miles/Day)	Work Trip Fuel Cons. (Gal/Day)	WORK TRIP AUTO EMISSIONS (Kg/DAY)		
	DRIVE ALONE	SHARED RIDE	TRANSIT	VANPOOL			HC	CO	NO_X
BASE (AVG/TRIP)	0.78	0.19	0.03	0.0	12.80	1.05	0.13	1.85	0.05
POLICY									
Increase Areawide Park Cost +$1.00	-1.6	5.3	8.7	-	-0.9	-0.9	-0.9	-0.8	-0.9
+$2.00	-3.4	10.9	18.4	-	-1.9	-1.8	-1.8	-1.7	-1.9

is roughly equivalent to the introduction of "self-pay" parking; that is, employee parking costs would not be fully subsidized by their employers but paid directly by those using the parking facilities. Such a policy is projected to result in a .9 percent decrease in areawide work VMT, approximately five times greater than that achieved when the parking increase is applied only in the central business district (Table 7-8).

Two of the parking policies examine possible relocations or reductions in the supply of parking in downtown Denver. The result of a 10-minute increase in round trip walk time in the central business district between the parking location and the place of employment is an 18.1 percent increase in CBD transit ridership and a 2.1 percent reduction in CBD work VMT.[1] Comparing the effects of parking cost increases with longer walk times, the effects of the $1.00 increase in CBD parking cost are approximately equal to an increase of eight minutes in round trip walk time at the destination.

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[1] This policy is equivalent to doubling the out-of-vehicle walk time for the 76 percent of CBD parkers which the 1970 survey showed had a five minute one-way walk.

SUMMARY OF FINDINGS

1) Parking in Denver traditionally has been both plentiful and low cost. With a minimum of regulation, parking is an important component of the downtown business economy. Parking derived revenues are an important source of income to both the City's general fund and the Urban Renewal Authority.

2) While there is sufficient total parking to meet demand at the time of maximum parking accumulation, the 15 percent of excess capacity is highly fragmented and not ideally located. Seventy-five percent of downtown parking is occupied by commuters, and the areas of highest shopping are also the highest locations of workers. Consequently, convenient parking for shoppers and other non-work travellers is in tight supply.

3) To be effective, parking management should not be limited to downtown Denver but should apply areawide. This implies that RTD's current park and ride program should be considered as an integral component of an areawide parking management program. Further, this implies that parking management could apply to employer provided facilities as well as to community and on-street spaces, and that the specific measures include pricing as well as supply limitation mechanisms.

4) Parking measures which are designed to increase carpooling incentives and to increase the availability of short-term parking for retail business appear to be attractive in Denver in terms of meeting desirable goals and are feasible with relatively few adverse impacts. The development of Denver's park and ride system and the promise of improved bus service

to the downtown area weaken the frequently-used argument that parking should not be managed because there are no alternatives to driving.

5) Parking management strategies can be appropriate for meeting a variety of Denver urban area objectives, and need not be sold primarily on the basis of air quality. In addition, they need not be onerous when carefully planned to avoid anticipated adverse impacts. While parking measures potentially can result in adverse economic impacts, these negative effects can be avoided through design.

6) Several agencies in Denver currently have partial control over parking, but no existing agency can exercise control over all others, and no agency currently exercises control over private parking rates or facility size and location. Consequently, there is currently no well-defined single institutional mechanism for easily implementing a parking management program.

7) Current parking capacity is such in the downtown area that parking measures are limited, but still meaningful, in their short-run ability to reduce VMT. Reductions of 1-3 percent are possible in CBD work trips for the strategies analyzed, with regionwide reductions of 1-2 percent forecast. Parking management can be most effective in the short-run within the highly localized downtown area. Furthermore, it can be effective as a long-term strategy in reducing the growth of VMT, promoting the use of transit, increasing the economic viability of the CBD, and promoting the overall aesthetic appeal of downtown Denver.

8) Staged implementation of a long-term parking management plan, in coordination with improved transit and other actions to improve the strength of downtown Denver, would not be costly to administer and could be designed so as not to decrease current parking revenues. Still, given the large number and strength of private parking operators, it would be time consuming and difficult to design, negotiate, and implement a successful plan.

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CHAPTER 8

BICYCLING

BACKGROUND

Denver's relatively flat topography and moderate climate make it well suited for bicycling, and cycling was an extremely popular pastime in the 1890's. The popularity of the bicycle declined with the increasing availability of the automobile to all income groups, and the city's major growth took place in an era when the automobile was viewed as an indispensable part of life. A renewed interest in bicycling surfaced in Denver in the late 1960's and early 1970's, prior to the huge surge in popularity which bicycling has enjoyed across the country.

The development of an integrated strategy for bicycle use was included in the Denver Transportation Control Plan, specifically the construction of a pilot route from an outlying residential area to the downtown to give an improved estimate of the usage for a proposed 164 mile bikeway system. Denver's bicycle facilities had been the object of considerable local study prior to their inclusion in the TCP, and consensus on a plan of action for improving the facilities had been reached. In this respect, the bicycle component of the TCP is unique because it already had widespread local support and would have been pursued regardless of the status of the TCP. A Denver public official has observed:

> Experience we have had with transportation control strategies in Denver over the past four years would seem to indicate that strategies such as bicycle lanes may be the most implementable and publicly acceptable of any strategies proposed to date for Denver. I should point out also that the bike lane program in the Denver area has been recognized internationally as the most sophisticated in the United States. Furthermore, there is significant commitment to the implementation of this program at the local political level (1).

Our investigation indicates that Denver's bikeway facilities provide an economical, cost-effective means of achieving modest savings in vehicle miles travelled. The presence of a bikeway system is considered to be an asset to the city, and increased bikeway use is considered to be a desirable non-threatening means of reducing automobile use. However, an examination of the timing of Denver's bikeway planning and implementation indicates that progress on the bikeway system has been largely unrelated to the fact that bikeway development was an element of the Denver Transportation Control Plan. In fact, political support for the construction of bicycle facilities waned in the mid-1970's, and only recently has been revived with the formation of a new bicycle-oriented public interest group, inclusion of a statewide bicycle program as an element of the Colorado Energy Conservation Plan (2), and the availability of new funding through the Federal Aid Highway Program.

THE DENVER BIKEWAY PLAN

Bikeway Routes

"On September 17, 1971, the Denver City Council unanimously adopted a resolution 'requesting the Planning Office to perform a study, develop a master plan and propose a pilot project (demonstration route) pertaining to a bicycle way system in the City and County of Denver...' The resolution cites:

> The need to create an efficient means for transporting people which will minimize noise, congestion, and air pollution;
> The necessity for development of alternative modes of transportation;
> The appropriateness of the bicycle in terms of the environmental consequences;
> The ideal climate and topography for bicycling in Denver;
> The present inadequacies of the street system for handling bicycles safely; and
> The need for providing bicyclists with the measure of protection to which they are entitled." (3)

The end product of this effort, published in October, 1972 by the Planning Office, was a plan for a 164-mile bikeway system for the City and County of Denver (Figure 8-1), and a 14-mile pilot route, extending to the east and south of the Civic Center (Figure 8-2). A bond issue was proposed and approved by City Council as the most effective way of initiating construction on the ambitious bikeway system, as neither the city's Department of Public Works nor the Parks Department had the resources to fund the "big splash" that supporters of the system felt was necessary.

According to the February, 1977 Denver Planning Office Map, approximately 136 miles or 83 percent of the system has been completed, with 50 miles of on-street facilities signed and 86 miles of off-street bikeways either constructed or under construction. About half of the core 14-mile pilot route network are off-street facilities.

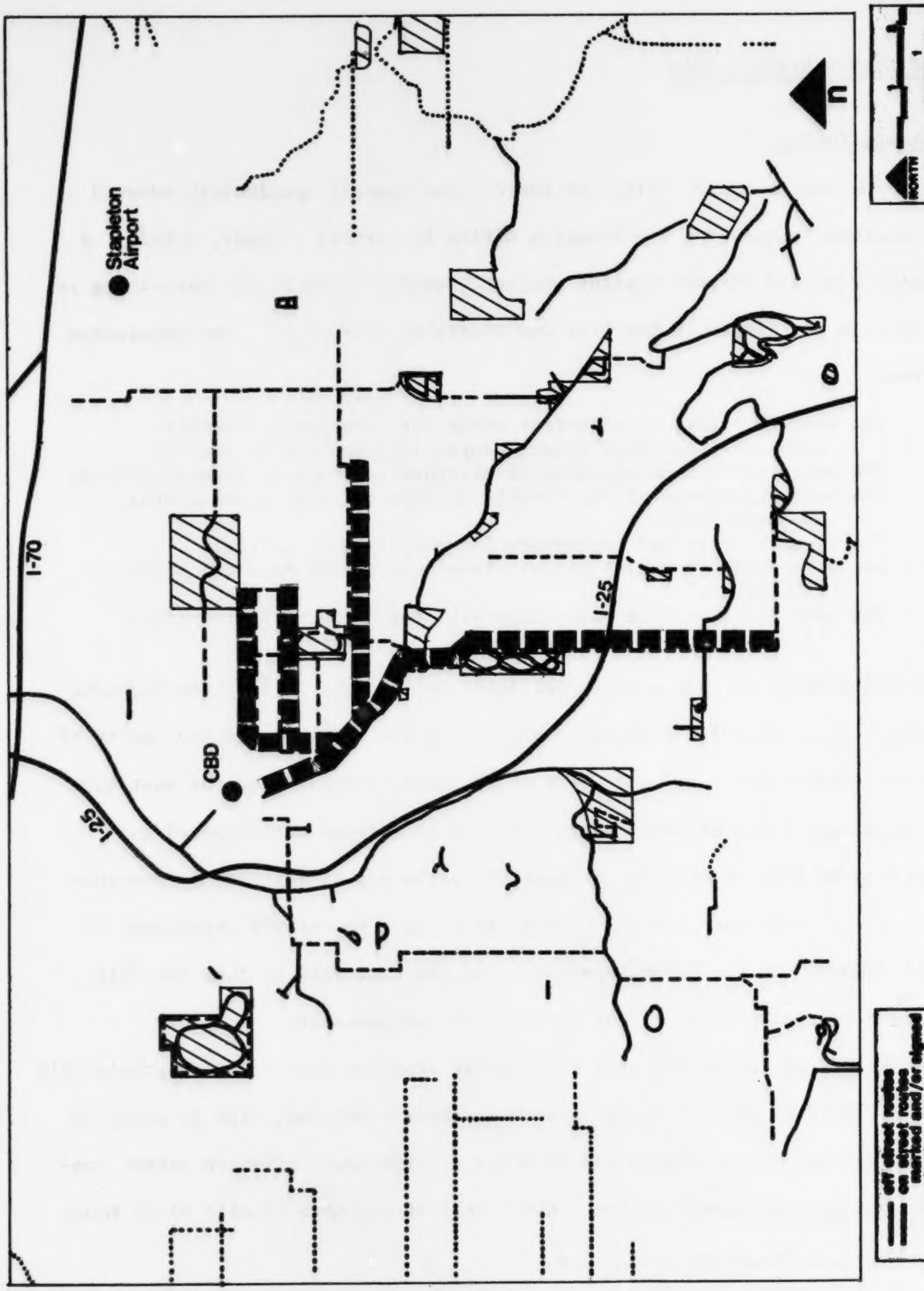
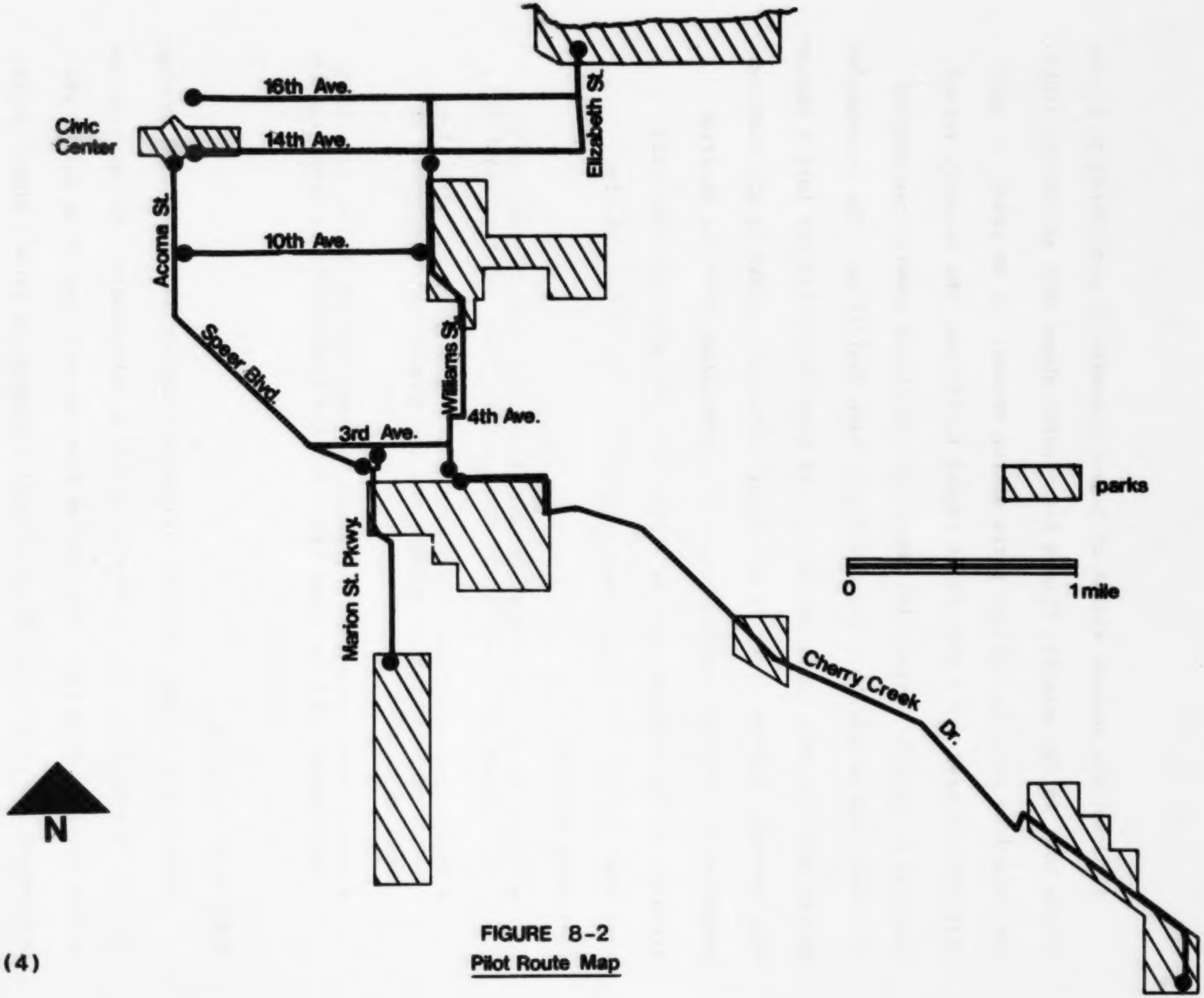

I-70
Stapleton Airport
CBD
I-25
I-25
off street routes
on street routes marked and/or signed
suburban connectors
public parks
most heavily used routes
NORTH
feb. 1977
1
miles

FIGURE 8-1
Denver Bikeway System


16th Ave.
Civic Center
14th Ave.
Elizabeth St.
Acoma St.
10th Ave.
Speer Blvd.
Williams St.
4th Ave.
3rd Ave.
Marion St. Pkwy.
parks
0
1 mile
Cherry Creek Dr.
N

Source (4)

FIGURE 8-2
Pilot Route Map

Although the present system of Denver bikeways is considered to be one of the best in the country, Figure 8-1 clearly shows that additional links are needed to join the various parts of the system. In an effort to meet this current need for a network of linked facilities, the recently formed Mountain Bicyclists Corporation (MBC) has identified several recommended on-street routes which are not now signed bike facilities. The recommended routes have two main foci, one is to link existing facilities into a region-wide network, and the other is to improve commuter access to the downtown Denver area. The recommended routes are shown along with the bonafide bikeways in the downtown area in Figure 8-3. In addition, MBC feels that some current routes are underutilized for one or more of the following reasons:

- routes do not serve high-use corridors, nor are they desirable for recreational riding; in other words, "they don't go anywhere";
- designated on-street routes are located along streets with high motor vehicle traffic volumes and are considered undesirable as well as unsafe;
- insufficient attention was given in route designation to bicycling impediments such as large hills and the presence of railroad tracks.

Bikeway Maintenance

Maintenance of the existing designated bikeways is not uniform throughout the system, according to Denver bicycling enthusiasts. Representatives of the Mountain Bicyclists Corporation have recently cycled on all of the designated bike routes and found several instances of broken glass, rocks, a dirt slide, and protruding branches, all of which compromise bicyclists' safety.

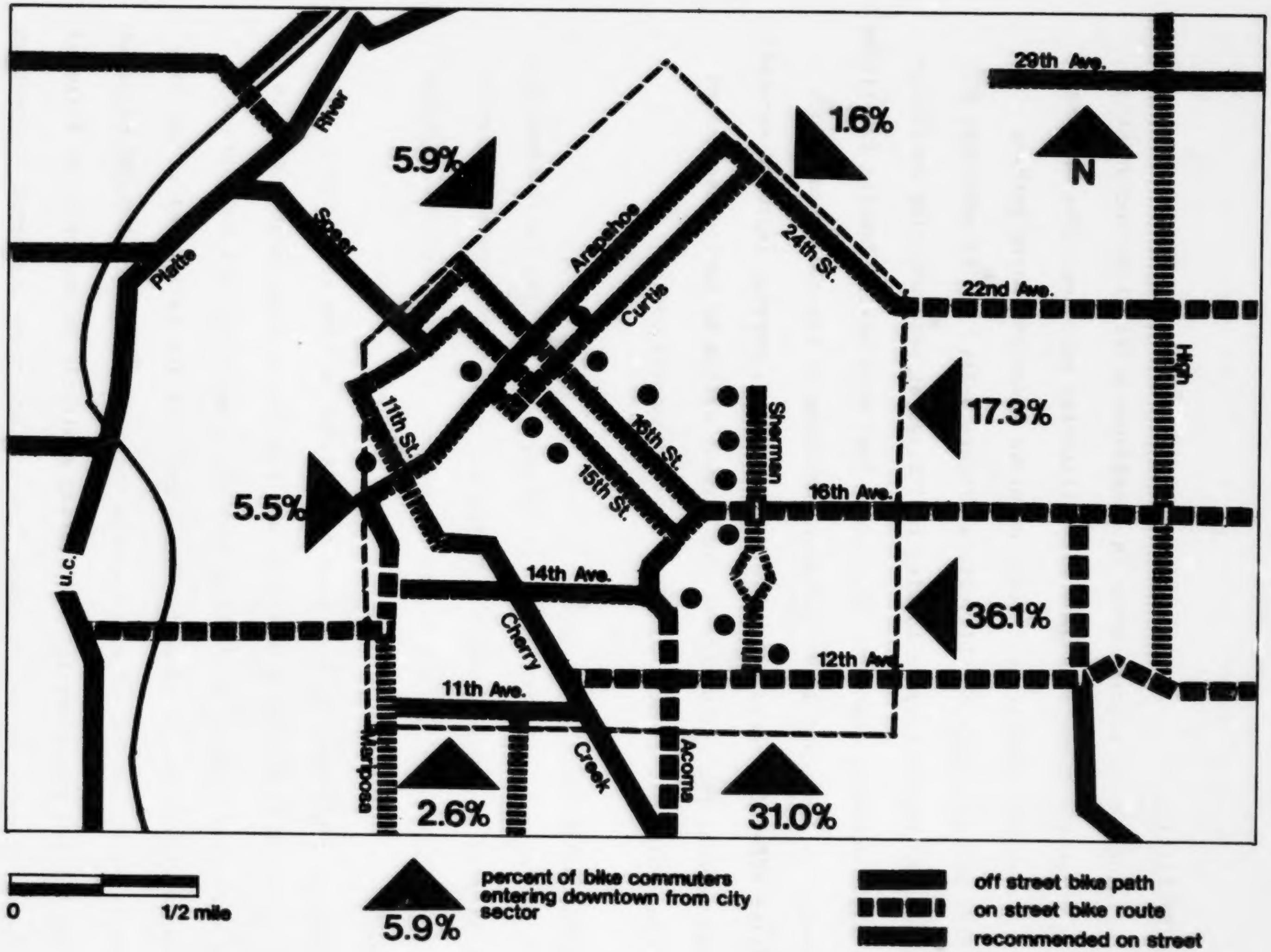

29th Ave.
N
1.6%
5.9%
River
Platte
Speer
Arapahoe
Curtis
24th St.
22nd Ave.
High
17.3%
Sherman
16th St.
15th St.
11th St.
5.5%
16th Ave.
14th Ave.
36.1%
12th Ave.
Cherry
11th Ave.
Creek
Mariposa
2.6%
Acoma
31.0%
u.c.
0
1/2 mile
5.9%
percent of bike commuters entering downtown from city sector
off street bike path
on street bike route
recommended on street
bike parking facility
CBD

FIGURE 8-3

Bicycle Routes and Parking Facilities in Downtown Denver

Source (5)

Parking Facilities

Providing secure storage areas is considered critical in encouraging trips in which the bicycle is used for utilitarian purposes. The Regional Bicycle Access Map identifies fifteen downtown locations where parking facilities are available for bicyclists (Figure 8-3)(5). In addition, RTD is planning to locate bicycle locking facilities at park-and-ride facilities and at major activity centers. Bicyclists feel that having locking facilities for bicyles is important in encouraging commuting by bicycle because such facilities offer increased convenience to cyclists, provide improved security, and also improve the visibility of the bikeway system by having designated facilities which are clearly oriented toward commuter use.

Registration and Safety

In addition to facilities such as bikeways and parking facilities, the Denver bicycle system includes a registration component. The registration program is mandatory at the county level, but it is not currently being enforced.

Bicycle registrations increased from 18,000 in 1968 to 52,000 in 1972 in the City and County of Denver (6), and the Police Department's Bicycle Bureau estimated that in 1972 there were still approximately 100,000 unregistered bicycles. At present, 56,000 bicycles are registered in the City and County of Denver out of an estimated total of 200,000 to 300,000 bicycles.

The current procedure for registering a bicycle in Denver is as follows: take the bicycle to the neighborhood fire station to be inspected (inspection criteria are general operation and safety, e.g., brakes, reflectors, headlight, etc.), then mail the completed inspection form with the $1.00 registration fee to the Bicycle Bureau, and a metal registration tag is sent to the bicycle owner by return mail. The registration is valid for one year.

Legislation to change bicycle registration so that it is statewide is under consideration. The proposed system would involve a $5.00 registration fee, valid for two years. One dollar of the fee would be returned to dealers who would perform the inspection, $2.00 would go to the Colorado Department of Revenue for administering the registration system (this covers the cost of computerizing the information), and $2.00 would go to a user's fund for education, enforcement, construction of facilities, etc. A bill to create this statewide registration system, however, died in the Transportation Committee in 1977. Proponents now are looking for a bill to attach the proposal to as a rider, and also are looking for ways to put it on the Governor's legislative call in 1978.

INSTITUTIONAL RESPONSIBILITIES

The institutional setting for the planning and implementation of bikeways in Denver has evolved from the simple to the complex. In 1971, viewed simply, there was sufficient interest in bicycling for the City Council simply to request the Planning Office to perform a study of bikeways and to develop a master plan for bike routes. The City Council made a special appropriation for initial planning efforts, and the balance of the effort was paid for by regular Planning Office funds. Construction and/or signing of routes was financed by a local bond issue, the city capital improvements program, the Bureau of Outdoor Recreation, and private foundation funds.

The current institutional complexities derive from the fact that the City is no longer providing funds to support the implementation of the bikeway plan, and several other agencies have become involved in bikeway development because of their anticipated ability either to attract funds or to coordinate and provide expertise.

Implementation of the Denver Bikeway Plan

Following the appropriation by the Denver City Council for study and development of a master plan and proposal of a pilot route, an individual in the Planning Office was assigned responsibility for responding to the City Council request. The person who assumed this responsibility was an enthusiastic bicycle proponent, and his efforts were important in retaining the momentum and high level of interest in bicycling that had led to the City Council action. In an attempt to generate data on potential usage of the system, the Planning Office conducted a mode survey of selected downtown businesses and colleges, a general survey which appeared in newspapers and was distributed directly to bicyclists, and a cordon count. Based on this and other information, the bikeway system plan was developed and published in October, 1972, just thirteen months after the initial resolution by City Council. The plan included the fourteen-mile pilot route with approximately equal on- and off-street segments.

Following the development of the bikeway system plan, the Denver Planning Office played a minor role, with the major activities being in the two bikeway implementing agencies of the City, the Department of Public Works and the Department of Parks and Recreation. The DPW is responsible for signing, painting, and maintaining on-street bicycle routes, and the Parks Department is responsible for the off-street routes which run through the City's parks. The bikeway plan was used to formulate a year-by-year implementation strategy, and the DPW and Parks Department constructed mileage as funds became available. No major revisions to the plan were made, and funds have not been available for an ongoing planning effort by the Planning Office.

The individual who had been responsible for development of the bikeway plan left the Denver Planning Office and joined the staff at DRCOG where one of his responsibilities has been regionwide bikeway coordination. This left city bikeway responsibility in the hands of the two implementing agencies, neither of which assumed an overall coordination role.

Interest in the bikeway system remained high while routes were actively being constructed and/or signed. Bikeway activities, however, tended to decline in the mid-1970's following the expenditure of the $300,000 bond issue and the $100,000 capital improvements program because of increasing demands on the City's resources. The existence of other programs felt to be of higher priority made it undesirable to continue bikeway funding at the original high level, even though the system was not complete. In fact, in 1975, $100,000 was appropriated for bikeway construction, but the money was later rescinded and used for other purposes.

A recognition that the City was not likely to finance completion of the bikeway system in the near future has recently prompted bicycle enthusiasts to assume a more active role in overseeing Denver's implementation efforts, and in encouraging the attraction of outside funds through regional and state agencies. The increasing popularity of bicycling nationwide has resulted in a proliferation of potential funding sources for bikeway development, and efforts currently are underway to establish an institutional framework which will facilitate bikeway coordination and attraction of funds.

The following sections summarize the roles of agencies and groups currently involved in bikeway development.

Denver Planning Office

Since the completion of the 1972 bikeway plan, the Planning Office's only major effort has been the production of a bikeway system map, initially printed in 1975 and updated in February, 1977. As an indication of current DPO priority, the 1977 update consisted of a city graphic artist donating his time to revise the map, which then was printed with funds provided by a local savings and loan institution.

Department of Public Works

The DPW supports efforts to promote bicycle usage for commuter and recreational purposes, but because they have not received additional earmarked funding for bikeways, their recent activities have been minimal. In

1977, the DPW was encouraged by the Mountain Bicyclists Corporation to designate 12th Avenue as a bicycle route since it has lower levels of automobile traffic than the parallel designated bike route on 14th Avenue. Approximately 80 signs were erected along the five-mile route at a cost of about $20 per sign. This effort was funded from the traffic engineering budget, but the division does not have a very large budget for signing and the 80 signs for this facility were considered "a large dent."

The DPW does not view itself as having major responsibility for Denver's bikeway system and has made no attempt to attract funds from outside sources to continue bikeway development when it became apparent that the City would not continue funding at the original high level. Bikeway development is not a sufficiently high priority for the DPW to regularly commit departmental funds for signing additional routes.

Department of Parks and Recreation

The Department of Parks and Recreation performs its own engineering and construction for the approximately 86 miles of off-street bikeway facilities. In addition, it is responsible for maintenance, which they report generally amounts to about 3-5 percent of total project costs. The Parks Department has been involved in attracting funds from sources outside of Denver, such as the Bureau of Outdoor Recreation and is currently constructing portions of the Platte River bikeway.

Regional Police Safety Organization

The Regional Police Safety Organization (RPSO) was created by the Denver Police Department in June, 1974, to help coordinate a statewide bicycle safety program. The organization is currently involved in such activities as developing bicycle registration legislation, conducting a public awareness campaign using television spot-advertisements, organizing Bike-a-thons, creating a computerized information system to handle statewide bicycle accident data, and developing a reporting system which records all bicycle accidents in which injuries occur. The RPSO has been working with staff at the Colorado Department of Highways to identify opportunities for using highway safety funds for a data-base survey for accident reporting, and also for a program to educate police officers on bicycle safety considerations so that a reasonable enforcement program can be developed. The majority of RPSO's consciousness-raising promotional activities are oriented toward juvenile riders; however, registration and accident reporting will be applicable to riders of all ages.

Mountain Bicyclists Corporation

An organization called Bicycles NOW was formed at the peak of Denver's interest in the bicycle system, and the group was originally oriented toward commuting bicyclists. As the organization grew, its interests became more diverse, eventually becoming "too environmentalist" for some of its members. As a consequence, Bicycles NOW was phased out and the Mountain Bicyclists Corporation (MBC) was formed to act as an umbrella group for bicycle concerns and to focus on statewide bicycle issues. MBC received financial support from the Environmental Protection Agency, the Colorado Department of Highways, and RTD to host a statewide conference "...to identify problems and their solutions for the advancement of bicycling in Colorado" (7). The conference took place on April 4 and 5, 1977, and it promoted MBC into a visible position as a voice for statewide bicycle concerns.

The strongest recommendation to come out of the conference was to identify a state lead agency for bicycles. While a state-funded bicycle advocate position was contemplated, the most expedient course of action currently appears to be the establishment of a position of statewide bicycle coordination within the Colorado Department of Highways.

MBC representatives have been riding all of the existing bikeways in the Denver area and formulating recommendations on maintenance, current use, and priorities for future construction. Relocation of the bike lane from 14th to 12th Avenue was one of the recommendations resulting from this effort.

Denver Regional Council of Governments

The Denver Regional Council of Governments has been responsible for coordination of bikeway planning at the regional level. Their activities include the establishment of uniform standards for construction and signing so that there is continuity when a bicyclist is travelling on a route that is in more than one jurisdiction. DRCOG also has been concerned with assisting areas in developing a process for bikeway planning that includes considerable citizen involvement. Several of the planning and implementation recommendations are contained in a report prepared by DRCOG entitled, "Regional Bikeway Systems Planning and Implementation" (6).

DRCOG also has provided information to local areas on various state and federal agencies which have programs for funding bikeway development, and has assisted them in preparing funding proposals.

Because the staff person responsible for bikeways has non-bicycle responsibilities as well and must allocate his bicycle-related time among all of DRCOG's constituent jurisdictions, he estimates that he spends approximately 5 percent of his time (or one day a month) on bikeways located within the City and County of Denver. Coordination between the DRCOG bicycle person and MBC is excellent, and information requests are often referred to MBC.

Colorado Department of Highways

The Executive Director of the Colorado Department of Highways recently issued a policy statement encouraging the development and safe use of bikeways in Colorado, and acknowledging that bicycling has been an acceptable mode of transportation "both within and beyond metropolitan areas" (8). One of the by-products of CDH involvement will be the inclusion of bikeways in urbanized areas' regional transportation plans, a requirement which will probably strengthen DRCOG's regional-level coordination role because of DRCOG's responsibility for the regional transportation plan. Increased availability of funds for both planning and construction is expected to result from CDH interest in bikeway system development, although the precise level of funding is unclear. An April, 1977, draft of the policy statement contained the following provision:

> It shall be the policy of the Highway Commission to allocate 1/2% of all Federal-Aid Consolidated Primary and Secondary funds, up to $200,000 annually, for independent bikeways on eligible Federal-Aid Systems. The Department urges local governments to follow a policy of allocating 5% of their urban system funds to independent bikeways (8).

However, this provision was eliminated by the State Highway Commission during their deliberations. A representative of the Mountain Bicyclists Corporation explained that it has long been the policy of the State Highway

Commission not to earmark funds, so that the bicycle projects will compete with all other proposed projects for funding.

Regional Transportation District

Denver's Transit agency, RTD, recently has become active in expanding opportunities for cyclists by permitting bicycles on intercity buses and undertaking a program of bike rack facility installation. The bus which operates between Denver and Boulder accepts bicycles, and although the number of riders who use this service has not been determined, RTD staff feel that most of the people who take their bicycles on the Denver-Boulder bus are Colorado University students.

RTD hopes to install bike racks at all park-and-ride lots, at major activity centers, at key points where bike routes cross bus routes, and at several locations where bus shelters have been or will be constructed. Locking facilities for bicycles are expected to be installed in 20 locations this year. The racks that RTD has purchased each accommodate two bicycles, and two of the racks will be placed at each site. RTD has worked with people in municipal governments to determine the most appropriate locations for the bike racks; in Denver, RTD's contacts have been in the Department of Public Works.

ANALYSIS OF PROGRAM IMPACTS

In the 1973 Denver Transportation Control Plan, it was estimated that increased bicycle use would result in a 1 percent reduction in automobile emissions by 1975. This section characterizes the estimated impacts from encouraged bicycle use in Denver, in the process assessing the degree to which the TCP objective has been achieved. The following specific impacts are summarized:

- costs and funding
- system use
- safety
- travel time
- user cost
- VMT analysis
- health effects
- cost/benefit

Costs and Funding

Two types of costs relevant to bikeways are distinguished; one is the cost of planning the system and offering system support services (such as safety education) and the other is the cost of designing, constructing, and maintaining the facilities.

Planning and Support

A $10,000 appropriation by City Council was used to help pay for initial bikeway planning. Staff effort for the thirteen months that it took to develop the bikeway system plan was approximately as follows:

Denver Planning Office:	1 staff member full time for 12 months + 5 graduate students full time for 9 months
Parks Department:	2 months staff time
Department of Public Works, Traffic Division:	6 months

The total Denver Planning Office commitment on bikeway planning is estimated to have been $30,000; the remaining $20,000 of which came from regular department funds. Following completion of the bikeway plan, the ongoing effort by DPO has been minimal, and any staff effort either has been donated (as was the case for updating the bikeway system map in 1977) or has come from regular department funds.

The Denver Police Department pays the salary of the single full-time Regional Police Safety Organization staff member, and all other support for the organization is either donated (e.g., television spot advertisements) or will be funded by an increased bicycle registration fee (e.g., a computerized record system).

The staff member at DRCOG whose responsibilities include regional coordination of bikeway planning spends only about 5 percent of his time on issues related to the City and County of Denver bikeway systems. His salary is paid out of regular DRCOG funds.

The Mountain Bicyclists Corporation relies on funding from several sources. They received funds from EPA, RTD and CDH to conduct the April statewide seminar, and they are currently seeking funds from EPA to undertake the Regulation 9 mandated promotion of bicycle use among Denver employers.

Facility Construction

General cost estimates for construction of bikeway facilities are (9,10):

$20,000 - $30,000 per mile - Class I, separated right-of-way, exclusive bicycle use
$ 2,000 - $ 3,000 per mile - Class II, restricted right-of-way, exclusive or semi-exclusive bicycle use
$ 500 - $ 1,000 per mile - Class III, shared right-of-way

In Denver, the Department of Public Works estimates that signs for on-street bike routes cost approximately $20 each installed, and they typically place signs at 1,000 foot intervals along on-street bike routes. The cost of an on-street bikeway will vary depending on the number of curb cuts required, and the amount of pavement marking that is desired. The cost of off-street routes depends on whether or not it is necessary to purchase land for the right of way, the desired width and grade of the facility, the sub-surface and drainage characteristics of the roadbed, and on whether or not structures such as bridges or overpasses are required. While it was not possible to obtain an allocation of per-mile costs of specific facilities, Table 8-1 contains a summary of overall construction expenditures.

CDH has constructed or programmed for construction 22 miles of bikeways statewide since December 1975. These facilities are incidental to Federal-Aid highway projects and represent a commitment of $424,000. An additional 22 miles of bikeways have been approved at an expected cost of $381,000. These facilities comprise three bikeway demonstration projects (8).

The bike storage facilities which RTD is planning to install cost $90 each (one unit accommodates two bicycles), and will cost an estimated $400 to install if a concrete pad has to be poured. If the rack can be located on an existing sidewalk or comparable concrete surface, the cost of installation will be somewhat lower.

TABLE 8-1

Construction Expenditures for Denver Bikeways

Expenditures	Funding Sources
$50,000 for pilot route network	City Council
$300,000	1972 Bond Issue
$100,000	Appropriation by City Council - Portion of capital improvements program earmarked for DPW expenditure on bike routes
$150,000	Bureau of Outdoor Recreation
$750,000	Private foundation - for development of Platte River segment

Source: (6)

System Use

The current level of use of Denver's bikeway system is not known with certainty, as recent bikeway efforts have focused on increasing the number of route miles available to cyclists rather than on assessing system use. Still, some implications can be drawn from an examination of available data, factors known as indicators of bicycle use, and estimates of the current level of use made by Denver cyclists.

The most recent cordon count was conducted during the last two weeks of October, 1971, prior to the construction of any bikeway facilities. The count showed that:

- between 7 AM and 11 AM 436 cyclists entered the CBD
- the peak hour was from 7:30 to 8:30 AM when 200 cyclists entered the CBD; the comparable automobile peak flow occurred between 7:00 and 8:00 AM when 18,200 vehicles entered the CBD
- 15 percent of bicyclists entered the CBD on East 12th Avenue
- 67 percent of the cyclists entered the CBD from the southeast quadrant (3).

Also prior to bikeway construction, the Denver Planning Office conducted a general survey of bicycle use by publishing a questionnaire in local newspapers and by distributing forms directly to bicycle riders. There were a total of 1,428 responses, 960 of which were used in tabulating results (responses from bicyclists under age 18 were not used). The survey showed that:

- 60 percent of respondents made 5 round trips per week
- 40 percent of respondents travelled 11-20 minutes one way
- 39 percent of respondents travelled 1-3 miles one way
- 26 percent of respondents travelled 3-5 miles one way
- approximately 70 percent of respondents lived in the east, southeast, and south parts of the city.

The Mountain Bicyclists Corporation feels that, although the ridership levels have increased substantially since these counts were taken, the distribution of bicyclist origins and trip characteristics has remained unchanged between 1971 and the present. (Cyclist origins are shown in Figure 8-3.)

In addition to the cordon count and the general survey, a mode survey also was conducted in 1971 among employees of eight downtown businesses and students of two downtown colleges (Table 8-2). It was found that 7 percent of the individuals surveyed used bicycle, 71 percent used cars, and 17 percent used bus.

TABLE 8-2

Modal Survey of Denver Downtown Colleges and Businesses

Response	Modal Share (%)					
	Car	Bus	Bike	Motor-Cycle	Walk	Other*
College Student	68	17	9	1	4	1
Business Employee	74	17	5	1	3	0
Total	71	17	7	1	3	1

* taxi, truck, or hitchhiking

Source: (3)

Recent counts are limited to one-time counts during 1973 at eleven locations along the pilot route and comparison counts at two 14th Avenue and 16th Avenue locations on the pilot route. The 14th Avenue lane showed a 29 percent overall increase in use from October, 1972 to May, 1973, and the 16th Avenue lane showed a 35 percent overall increase in use from October, 1972 to June, 1973.

While no recent systematic volume counts have been made, the Mountain Bicyclists Corporation estimates that as many as 7,000 people currently commute to work by bicycle in the Denver area during the summer months, and that this number is reduced by approximately half during the winter. Another source estimated 7,000 bicycle commuters to the CBD alone during the summer, but MBC feels that this number is high, and that 7,000 people countywide is a more reasonable estimate.

MBC has identified the following routes as the most frequently used bicycle corridors:

- Franklin Street - Washington Park - Marion Parkway
- Cherry Creek Bikeway from Downing to the CBD
- Acoma from Cherry Creek to 14th Avenue
- Seventh Avenue from Colorado Boulevard to Cherry Creek
- Twelfth Avenue from Colorado Boulevard to Sherman Street
- Sherman Street from Twelfth Avenue to Sixteenth Avenue
- Sixteenth Avenue from York Street to Broadway.

These highly travelled routes are identified in Figure 8-1.

A focus of many bikeway efforts, particularly those done as part of TCP's, is increasing the number of purposeful trips made by bicycle on the assumption that some of the trips would normally have been made by automobile. In a discussion on estimating the type and volume of purposeful bicycle trips, Carl Ohrn (11) concludes that commuter trips may not be a particularly appropriate focal point for efforts to increase purposeful bike trips, since the commute trip "...is typically the longest of all urban trips, must be performed on a rigid schedule, and has the best transit option." Ohrn feels that the greatest number of purposeful bicycle trips will be drawn from the present automobile passenger trips; that is, trips that are made just to accommodate the passenger. Ohrn also feels that a relatively small number of trips would shift from transit to bicycle since the majority of transit patrons are either elderly or commuters. Ohrn feels that bicycles could account for 8.7 percent of total home-based vehicular trips (even though transit now accounts for only 2.7 percent of home-based trips). Barton-Aschman studies have found that at present, however, of the 40 percent of Americans who bicycle, only 15 percent do so for purposeful trips, and of the purposeful trips, only 20 percent were work trips (12).

In addition to work trips, Denver area cyclists feel that a large number of the purposeful trips by bicycle are trips from home to school. Cyclists in this category include primary, secondary, and high-school students, as well as college students.

Safety

In examining potential safety impacts of increased commuter bicycling, it is important to differentiate existing accidents by type of facility and age of rider. The National Safety Council (NSC) has reported a variety of statistics on bicycle accidents for 1972 (6):

- 97 percent of all bicycle injuries and deaths result from collisions with automobiles
- 50 percent of the fatalities were in the 0-14 year-old age groups.

In 1970, NSC recorded trip purpose when the accident occurred:

- 0.3 percent of accidents occurred during work trips
- 54.5 percent occurred while "riding around"

In Denver, 200 bicycle accidents were reported to the police in 1970, twenty of which had incomplete data. Of the remaining 180, the breakdown was as follows:

Age	Number	Percent
Elementary (up to age 11)	77	42.8%
Junior/Senior (12-17)	66	36.7%
Adult	37	20.5%

One fatality was included (adult), and 47 bicyclists had to be carried from the scene of the accident to the hospital (6).

Safety is a concern in promoting increased bicycle use because other areas, such as Boston, have found that the number of accidents increases as the volume of bicycle use increases. A Pennsylvania bicycle users survey indicated that safety considerations were the key factor in discouraging use by 16 percent of users and 6 percent of non-users (13).

Although off-street bikeways generally were favored from a safety point of view, they do have drawbacks. Intersections are the scene of the majority of bicycle accidents, and it is claimed by critics of separate facilities that bicyclists are less aware of their vulnerability when riding on such facilities, and therefore are more likely to have accidents when the bikeway crosses major streets. From a ridership viewpoint, bicyclists making purposeful (as opposed to recreational) trips generally favor the most direct routes to their destinations, and it is not usually possible to acquire rights-of-way for Class I separated facilities which are as direct as streets in major commuting corridors. Despite these drawbacks, it is commonly perceived that off-street bikeways will improve safety.

Travel Time

Studies have shown that for commuter trips up to 4-6 miles in length, bicycling can be competitive in travel time to that of the private auto. For example, in an article entitled, "Bicycles for Transportation," (14) Dewey Chiesl assesses the time savings that can be realized with bicycle commuting. Assuming that a bicyclist can comfortably commute for ten miles at 12 miles per hour, Chiesl first compares average commute distances and automobile speeds in U.S. cities:

	Average Distance	Average Speed
Chicago	6.3	15 mph
Minneapolis/St. Paul	4.9	22.1 (non-freeway)
	9.7	29.5 (freeway)
	6.9	22 (average)

A car travelling 6.9 miles at 22 mph takes 18.8 minutes, whereas a bicyclist travelling at 12 mph would require 34.5 minutes, or an extra 15 minutes over the automobile travel time. In Denver, the average CBD commute trip distance is 7.67 miles and the average speed is 22 mph; areawide average trip distance is 7.26 miles and average speed is 25.2 mph. This results in auto travel times of 20.9 minutes for average CBD work trips and 17.3 minutes for areawide work trips. Using the assumption of 12 mph bicycle travel time yields travel times of 38.4 minutes for the average Denver CBD work trip and 36.3 minutes for the average areawide work trip. Thus the bicycle trip times are approximately double -- 17.5 and 19 minutes longer -- the automobile times for the average commuter trip length. It can be argued, however, that travel time comparisons for the average trip do not tell the whole story in analyzing bicycle versus auto commute times, as the car driver consumes time starting the car, warming it up, clearing windows, locating a parking space, parking, and then walking to the place of work. The total time consumed in these activities, when added to auto travel time, minimizes the differences between the two modes. If it is assumed that ten minutes is required for these out-of-vehicle activities, then bicycling in Denver becomes time-competitive with the auto at trip lengths of approximately four miles. Further, it is estimated that in the order of 40 percent of all commuters have trip lengths less than or equal to this distance, thereby defining the most likely market segment for bicycle commuting.

User Cost

The cost of purchasing and operating a standard size 1976 automobile and driving it 10,000 miles per year for ten years has been estimated as $17.88 cents per mile or a total of $17,880, including depreciation, maintenance, fuel, insurance, parking, tools, and taxes (15). Assuming a bicycle cost of $150 and maintenance of $30 per year, the same amount of money would buy 40 ten-speed bicycles and provide for their maintenance for ten years (14). Using these same bicycle cost estimates and assuming that the bicycle is used exclusively for commuting to work for a one-way trip of approximately six miles or about 3,000 miles per year, the cost per mile is:

$45/yr./3,000 miles = $.015/mi. (5)

or a per-mile difference of 16.4 cents per mile relative to a standard-size car.

VMT Analysis

Several factors combine to make a detailed analysis of the actual VMT reduction attributable to increased levels of bicycle ridership in Denver difficult. The incomplete information on existing bikeway system use makes use estimates fairly rough. For example:

- The level of current use of the bicycle system is not known. The most recent cordon counts were performed in 1972, prior to the construction of the bikeway system.
- The former mode of bicyclists is not known but is critical in accurately determining VMT shifts.
- It is not known how significantly winter ridership differs from summer ridership, nor is it known what mode cyclists use in inclement weather.

Additionally, major VMT impacts are expected when commuting by bicycle becomes more widespread, on the assumption that most of the new cyclists will have shifted from automobile travel.

Because the Denver bikeway system is not yet complete and because the routes which have been constructed do not provide cyclists with good access to the downtown, the existing ridership can only give a rough picture of potential commuter use. Using the Mountain Bicycle Corporation's estimate of 7,000 riders in a peak summer day, which is thought to be a "realistic" regionwide figure; assuming an average bicycle one-way trip length of four miles; and assuming that the former mode of cyclists was 50 percent single-occupant auto and 50 percent transit, results in an estimated VMT savings of 28,000 miles per day or a .5 percent reduction in areawide work trip VMT.[1]

Another way of calculating VMT saved is to use the number of CBD work trips and figure 7 percent are bicycle trips (the 1971 mode split, which is assumed to be conservative). Using the same average one-way trip length of four miles, and assuming former modes of 50 percent single-occupant auto and 50 percent transit, yields a VMT savings of 21,280 miles per day (using the 1975 figure of 76,000 total CBD work trips) or a work-trip VMT reduction of .4 percent.

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[1] The assumption of former mode is arbitrary but was selected on the premise that bicyclists are likely to have represented a higher-than-average proportion of transit riders. The VMT "savings" estimate also assumes no previous bicycle usage, which is unrealistic.

The 21,280 - 28,000 VMT saved per day represents approximately .2 percent of Denver's areawide total VMT, and although the estimates of existing bicycle use are probably conservative, the estimates still indicate that the order of magnitude of VMT savings that can be realized from increased bicycle use may be considerably smaller than anticipated in the TCP. This analysis also suggests that the 1 percent reduction in total urban VMT attributable to increased bicycle use assumed in 1977 in the Colorado Energy Conservation Plan (2) may be a high estimate. More detailed surveys on bicycle use in Denver will enable more realistic estimates of VMT reduction attributable to increased bicycle use.

Health Effects

It is often assumed that bicycling is healthful because of the physical exercise obtained and the absence of pollutants being emitted. There may be, however, certain adverse health effects on the bicyclist which should be considered. Although not yet verified by actual on-street data (18), laboratory studies indicate that bicycling in polluted areas may have a greater impact on the health of the cyclist than walking in polluted areas because the higher respiration rate of cyclists means a greater volume of pollutants are ingested. Because SO_2, particulates, and photochemical oxidants are regional air pollution problems, their impact on the cyclist is not influenced by the location of the bike route. Nitrogen oxides and carbon monoxide, however, are related to traffic conditions, but there is a time and spatial delay in the formation of nitrogen dioxide, making it also somewhat more of a regional problem. Carbon monoxide is the critical pollutant of concern in locating bicycle facilities, though the impact of CO decreases as distance from the travelled roadway increases (16).

The effects of CO on physical health are the same as those discussed in Appendix H, Urban Air Pollution and Health Effects; however, they occur more rapidly with bicycling because of a cyclists' elevated respiration rate.

Cost/Benefit

Several direct personal benefits have been cited for commuting by bicycle:

- flexibility in scheduling travel compared to single-occupant automobile;
- ease of parking (compared to automobile) and savings in parking fees;
- opportunity for exercise;
- substantial savings in vehicle operating costs;
- opportunity to experience physical environment more intimately;
- means of avoiding frustration associated with automobile commuting in rush-hour traffic;
- personal sense of satisfaction and accomplishment.

One means of assessing whether or not increased bicycle facility construction is justified is to perform a cost-benefit analysis. Although this technique cannot be used as the sole criterion in decisionmaking, it does provide a means of comparing potential routes and eliminating those routes for which fixed investment per rider is greatest.

Using a technique developed for Pennsylvania (17) to determine annual use from bicycle use counts taken in any month, a cost-benefit analysis was performed for the 14-mile pilot route shown in Figure 8-2. With the AM peak period ridership data obtained in the 1973 route monitoring counts (which are assumed to be considerably lower than present usage), the cost of the system ($50,000) averaged on a per-mile basis, and assuming a ten-year facility design life and a 10 percent interest factor, the following results are obtained:

1973 Count

Segment	Length (miles)	AM Peak Use	Benefit/Cost
Cherry Creek Drive	4.4	149	5.67
Williams Street	1.7	101	3.84
Tenth Avenue	1.2	97	3.69
Marian St. Pkwy	1.0	76	2.89
Speer Boulevard	1.8	64	1.35
Fourteenth Avenue	2.2	107	2.44
Sixteenth Avenue	1.7	110	4.18

This analysis is based on an assumed benefit of $.10 per mile to the cyclist. This figure is substantially lower than the operating cost savings of bicycle over automobile (average of $.10-.17 per mile) as an acknowledgement that not all cyclists used single-occupant autos as their previous mode. Also, the use of Pennsylvania ridership factors for Denver probably results in lower-than-actual estimates of ridership since Denver winters are less of an impediment to cycling than those in Pennsylvania. With respect to costs, ideally considerations other than facility costs should be included in the analysis, but as with benefits, many of these additional costs are difficult to quantify. As examples:

- decreased revenues to RTD resulting from diversion of riders to bicycles;
- increased potential for bicycle-automobile accidents;
- opportunity cost of spending resources on bikeways compared to funding other programs.

SUMMARY OF FINDINGS

1) Implementation of Denver's 164-mile bikeway system was 83 percent complete as of 1977, consisting of 86 miles of off-street facilities and 50 miles of on-street designated bikeways. In this respect, improved bicycle facilities have been relatively more successful than other measures contained in the TCP. However, while the system has had support from bicyclists and there have been no active opponents to bikeway construction, several factors have combined to slow bikeway implementation: institutional arrangements simply have evolved to accommodate bicycle activities without a well defined focal point of leadership responsibility; the original momentum that got the project off the ground was eventually lost as initial City funding sources were exhausted and competing demands for City funds assumed a higher priority; and the people who had devoted their energies to bicycles and were responsible for initial successes moved on to other work. Bicycling in Denver, in brief, has not yet achieved "transportation" status; it is still considered as a small-scale, semi-recreational activity. With responsibility falling to various agencies, bicycling does not receive either high priority or continued funding to enable plans to be fully and effectively carried through.

2) The planning of Denver's bikeway system began in 1971 with a resolution by the Denver City Council. Implementation of the subsequent Denver Planning Office prepared plan was supported by a $300,000 City bond issue approved in 1972. Thus, the initiation of improved bikeway facilities preceded the promulgation of an air quality transportation control plan.

Though air quality frequently is cited as a reason for bikeway implementation, realistically air quality and bikeway planning have proceeded in Denver in a largely independent manner.

3) Central to Denver's bikeway system is a 14-mile pilot route. A comparison of annualized construction costs to savings in user operating costs for seven segments of this pilot route yields benefit/cost ratios ranging from 1.4 to 5.7 with a median value of 3.7. For the system as a whole, regionwide summer usage is estimated as 7,000 riders per day, resulting in a potential reduction in work trip VMT of approximately .5 percent and in total daily VMT of about .2 percent. A major determinant for these VMT savings is the size of the market segment served by improved bikeway facilities. Travel time studies have shown that for most potential users, biking is considered to be competitive with the private auto for trips under 4-6 miles in length. Additional possible disincentives to increased bicycling are problems of safety and worsened air quality for the rider.

4) The availability of secure, convenient locking facilities is as critical a factor as improved routes for purposeful bicycle trips. Incentives for designation of locked storage facilities should be provided, including provision for increased use of public funds for destination area amenities.

5) Recreational and commuter needs for bikeways will not always be met with the same facilities. If a high priority objective is the use of bikeway facilities to reduce work trip VMT, then specific commuter-oriented facilities must be provided. Current attention is divided between recreational and commuting facilities.

6) One reason why bikeway facilities have proven to be politically popular is that they are easy to implement, low cost, and their use is voluntary rather than forced. As such, they are not perceived as a disincentive to the private automobile. Though the VMT savings are modest, bicycling provides many of the same "flexibility" benefits of the automobile in contrast to the "frequency" problems associated with ride-sharing and sometimes with transit.

7) Institutional responsibilities for bikeway implementation started with the City and County of Denver, but are now shifting to the region and state. Initial planning was performed by the Denver Planning Office, with implementation responsibility split between the Department of Public Works and the Department of Parks and Recreation. Neither of these implementing departments, though, exercised overall system coordination. Further, bikeway construction constituted a small and unspecialized part of City agencies' activities, and required no new personnel. Therefore, when City funds for bikeways ran out, there were no internal pressures (such as would be posed if individuals had been hired specifically for bikeway construction and had no other responsibilities) to seek outside funding sources to enable continuation of the bikeway construction program. Thus, when the original City funding sources ceased to be available in the mid-1970's for route construction and signing, local bicycle efforts soon lost momentum. While DRCOG could provide limited regionwide coordination, it required the availability of federal funding provisions and the formation of a new private bicycle interest group to re-activate visible bicycle interest. Recent initiatives have been at the state level, focusing on the State Energy Conservation Program and the Department of Highways. While this increased involvement

of the region and state is advantageous from the perspective of attracting funds and coordinating efforts of multiple jurisdictions, it is essential that this involvement of higher levels of government not eliminate those people who will be using the system. Most effective commuting routes will continue to be on local roads; input from cyclists is critical in bike route selection and design, with implementation responsibility being maintained by local areas and towns. Only well designed, well placed bicycle facilities can be expected to attract high ridership and thereby create a meaningful VMT diversion.

8) In examining the development of Denver's bikeway system, major accomplishments can be traced directly to single, highly motivated individuals and interest groups. This is not unlike the experience with other Denver TCP measures. What is needed now in order to return the City to its previous high level of bicycle activity is an aggressive advocate for bicycling to coordinate Denver's program and to identify opportunities for attracting funds for the implementation of expanded facilities.

9) The collection of data necessary to systematically evaluate the effectiveness of Denver's bikeway facilities is not perceived as a high priority activity by either local agencies or interest groups. The most recent complete cordon count was performed in 1971 prior to implementation of any new facilities, with limited facility counts performed during 1972 and 1973. With apparent, continued public support, emphasis has been placed on implementation and marketing -- not data collection. While

approximate usage estimates exist, the lack of reliable current assessments of effectiveness places bicycle interests at a disadvantage when competing for scarce public funding.

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CHAPTER 9

TRANSIT IMPROVEMENTS

TRANSIT IMPROVEMENTS AND THE DENVER TCP

Improvements in service designed to increase the percentage of trips made by transit have been included in numerous transportation/air quality plans. The justification for including transit improvements as a measure for improving air quality is twofold: by substituting the use of transit for private automobile use, pollutant emissions may be reduced; furthermore, better transit service can offset losses in accessibility due to proposed automobile restrictions.

In Denver, improvements to mass transit have been suggested both as a pollution reduction measure and as an air quality maintenance measure. Colorado's 1973 Air Pollution Control Transportation and Land Use Plan cites mass transportation's "great potential for long-term improvements in transportation-related air pollutant levels", but also suggests that significant short term improvements would result from such planned measures as expanded bus service, exclusive bus lanes, express bus routes, and provision of park and ride facilities (1). The EPA-promulgated TCP, based in large part on the Colorado plan and supplemental information submitted by the state, also includes transit improvements (2,3). The EPA regulation calls for bus/carpool lanes and, as a separate item, "mass transit improvements"; the latter are not specified, but the notice of rulemaking notes that Denver approved a transit plan in September 1973 and calls for that plan to be "amended to provide for as much...VMT reduction as possible."

The Colorado Air Pollution Control Commission's Regulation 9, which implements portions of the Denver TCP, requires the development and implementation of preferential treatment of buses and carpools, auto intercept parking facilities, and express bus service to employment and business centers (4). However, other expansions or improvements in transit service are not explicitly called for in the regulation.

Many transit related improvements are discussed in preceding chapters as they relate directly to other transportation air/quality measures; specifically preferential treatment of buses, park and ride facilities, and the provision of transit passes. This chapter reviews some additional region-wide and area-specific improvements to transit planned or implemented in Denver over the past several years, and examines the potential relationship between transit and air quality improvement.

REVIEW OF DENVER TRANSIT IN THE 1960's AND 1970's

Until relatively recently, Denver had little involvement with transit. With a low-density development pattern, high automobile ownership rates, and a well-engineered street and highway system, most Denverites found driving easy. Public transportation, provided by a number of private companies, attracted only about one percent of the trips made in the region.

By the late 1960's, however, support for transit had become vocal. The period 1960-1970 had seen a number of major changes in Denver. During this period the region's population grew by more than a third; over half of the growth was due to net migration, and much of it occurred in the suburbs. Transit ridership dropped by 60 percent as the financially troubled Denver Tramway System cut service and raised fares. Controversy erupted over proposed highways, which many citizens felt would facilitate further suburban growth at the expense of the city as well as damage neighborhoods and add to pollution. Environmental protection became a popular cause in Colorado, and Denver's serious air quality problem was of increasing concern. These many factors all contributed to a growing interest among businessmen, environmentalists, citizen groups, and city officials in a regional transit agency with authority to plan, construct, and operate transit facilities and services in metropolitan Denver.

In 1969, after considerable lobbying on the part of a variety of interest groups, the Colorado State Legislature established the Regional Transportation District (RTD) and empowered it to develop, maintain, and operate a public transportation system for the City and County of Denver, Boulder and Jefferson Counties, the northeastern portion of Douglas County, and the western portion of Adams and Arapahoe Counties (Figure 9-1). Under the Regional Transportation District Act, RTD was authorized to levy one-half mill on each dollar of assessed property valuation for planning

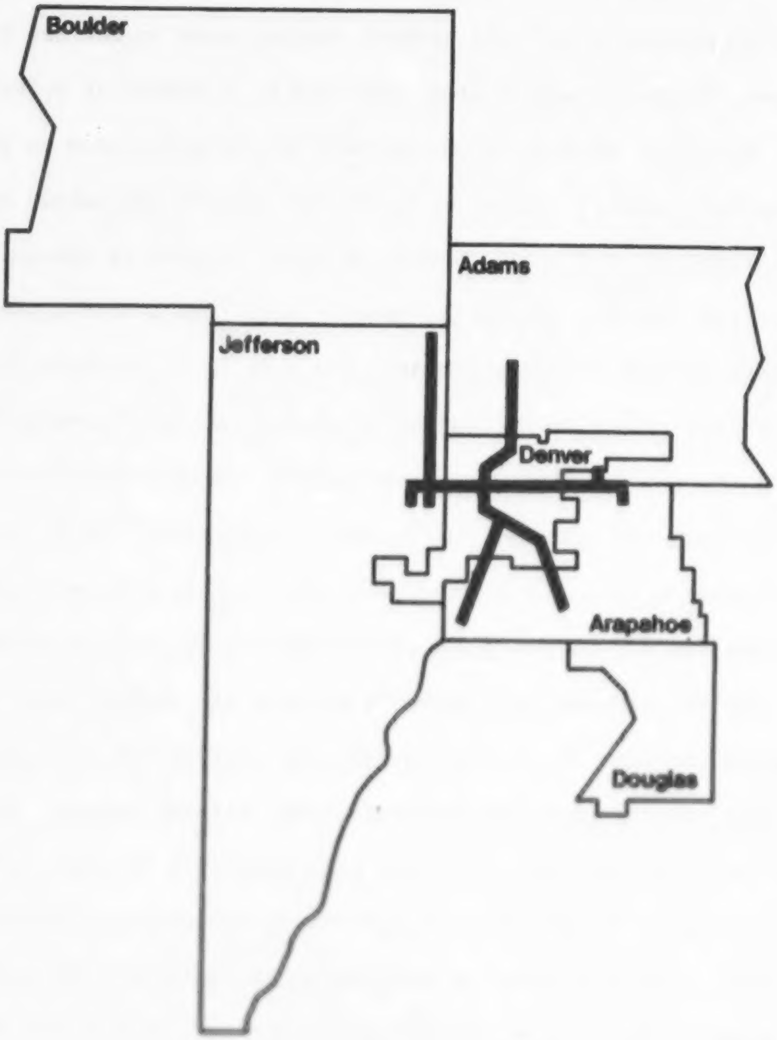
Boulder
Adams
Jefferson
Denver
Arapahoe
Douglas

FIGURE 9-1
RTD Jurisdiction and Primary Transit Corridors

and administrative expenses(6). The agency also was authorized to levy an additional two mills for the payment of any deficit in transit operations and revenues, subject to the adoption of a plan and voter approval of financing for it. RTD was given five years (until July 1974) to hold the referendum.

At the time RTD was created, the UMTA-funded Center City Transportation Project was considering a Personalized Rapid Transit (PRT) system from the Mile High Stadium to the CBD (5). PRT was considered to be attractive because it could provide service similar to that of a private auto, a factor deemed important in low-density, drive-alone Denver. When RTD began its transit planning, PRT was a familiar concept in Denver, and it enjoyed a fair amount of popular support. RTD thus focused on PRT in developing its initial transit plan.

In response to the public sentiments which had led to its creation, RTD sought to coordinate its transit planning with a land use/development program for the region. An interdisciplinary consultant team prepared a development plan which relied heavily on environmental factors such as carrying capacity and ecologic fragility to determine the best locations for future growth. The plan identified a series of "activity centers" where high density development and urban services such as transit would be concentrated (6). A few months later, UMTA announced that Denver would be the site of a PRT demonstration project and about the same time, RTD hired an executive director who was interested in PRT (7).

In June, 1973, the RTD proposed a 98-mile PRT-type system, using 12 passenger automated vehicles, and included an "Early Action Program" for immediate bus improvements (8). (A bus feeder system was to supplement the PRT system.) The PRT concept was endorsed by the Colorado Department of

Highways and DRCOG, and RTD put together a campaign to get public support for a financing plan to implement the plan. RTD also drafted and gained approval of legislation which allowed the use of a one-half cent sales tax to help finance the plan, if referendum approval was gained.

The subject of the referendum was whether to authorize the District to issue up to $425 million in revenue bonds backed up by one-half of one percent sales tax, but in its campaign literature, RTD tied the vote to PRT. In September, 1973, in a light turnout not atypical of referenda, 57 percent of the voters approved. RTD proceeded to search for consultants to do the preliminary engineering work on the PRT system and to prepare an application for a capital grant from UMTA.

Voter approval also meant that RTD could levy the up-to-two mill ad valorem property tax to pay for operating deficits, and in 1973 and 1974 RTD commenced implementation of its Early Action Bus Program. Using the sales tax revenues and UMTA and DOT grants, RTD acquired the Denver Metro Transit System (Denver Tramways had been acquired by the City and County in 1971), the Evergreen Transit Company, the Longmont Mini-Service Minisystem, the Northglenn Suburban System, the Denver-Boulder Bus Company, and the City of Boulder's share of the Boulder Bus System. New buses were purchased, construction of a new bus storage and maintenance facility was begun, and a program of park-and-ride sites and exclusive bus lanes was initiated (9). Integrating the various bus systems and upgrading both service and equipment was another badly needed and major chore for RTD. Thus, even though RTD's heart may have been with the development of its new transit system, it also took on the large and difficult task of getting Denver's bus service back on its feet.

By this time, however, UMTA had begun to show doubts about Denver's PRT proposal. Cost overruns in the Morgantown, West Virginia PRT demonstration and difficulties with Dallas-Fort Worth Airport's PRT-type Airtrans ground transportation system raised questions about the advisability of a major investment in an unproven technology. With too few funds to accommodate all capital grant requests anyway, UMTA was preparing draft regulations making a full analysis of alternatives a prerequisite for capital grants. When RTD asked for a study grant to continue work on its PRT system (known as DRT-demand responsive transit), UMTA responded by calling upon Denver to do an alternatives analysis.

RTD already had begun interviewing candidate consultants to design and manage construction of the DRT system when the UMTA request for an alternatives analysis was made. Therefore, the alternatives analysis was added as an extra task in the consultants' work program (7). The consultant team carried out the study rather quickly, preparing their report by April, 1975, and recommending an 80-mile fixed guideway system --an "Automated Rapid Transit" (ART) system--supplemented by bus (10). ART was expected to be simpler and less expensive than the DRT proposal; it would utilize larger vehicles and would serve the activity centers identified in the earlier development study. The first segment, 28 miles long, was to run north and south from the CBD, from Littleton to Northglenn. The total capital cost through the year 2000 of the proposed ART system was about one billion dollars, as compared to $1.8 billion for the DRT system (9).

The MPO (then RTD, RCOG, and CDM) approved the ART plan in June, 1975, following public hearings where the plan was accepted by most groups after RTD promised that a transit route would be imposed on an unreceptive neighborhood. After several months review, however, UMTA asked for additional consideration of bus and light rail. In February 1976, the RTD Board modified its proposal, calling for a 23-mile, 14-station light rail system in the Littleton to Northglenn via the downtown corridor. The light rail system would be located in the same corridor as was proposed for ART; the main change was to the "proven" light rail technology. The capital cost of the system was estimated at about $700 million.

RTD's analysis showed that buses could handle the projected volumes for about ten years. However, RTD argued that the eventual costs of converting busways to rail rapid transit would be greater than the cost of building transit at the outset, so that light rail was the wiser investment.

Meetings between UMTA and senior Colorado officials, including Governor Richard D. Lamm, Denver Mayor William H. McNichols, Jr., and the members of the Colorado Congressional delegation occurred throughout 1975 and the first half of 1976. UMTA had three major doubts about RTD's rapid transit proposal. First, technical questions arose about the methods and assumptions in the cost-effectiveness analysis. In particular, RTD's use of a low discount rate (4% compared to the OMB-recommended 10%), which was responsible for rail looking relatively good compared to bus. Second, UMTA concluded that bus service could attract as many Denver area riders in the short term as rail for a lower cost, and other cities with higher population densities were in greater need of rapid transit. Third, UMTA Headquarters officials apparently were concerned that Denver was unwilling to take steps to discourage auto use, relying instead on transit's attractiveness to increase ridership (14)[1]. In June 1976, UMTA rejected RTD's proposal as "premature", noting that Denver's own analysis showed that an all-bus alternative involving exclusive busways could serve the same ridership as the proposed light rail system at one-third of the capital cost and at a significantly lower combined capital and operating cost (12). UMTA indicated its willingness to consider substantial funding for bus system improvements and to make loans for advance acquisition of property needed for the preservation of the rail transit option.

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[1] There also was some concern that the Ford Administration did not look favorably upon Colorado and would not be predisposed to giving Denver a major chunk of increasingly scarce transit funds.

RTD has not given up on a rapid transit system; it recently reaffirmed its support for the Public Transportation Plan for the year 2000 (13). However, staff members say that in view of the shortage of UMTA monies and President Carter's skepticism about rail transit, RTD does not anticipate submitting another rail proposal until 1980 - 1981 at the earliest. Headquarters staff shrank from 223 to 150 positions as a result of the UMTA turn-down; this allowed RTD to meet its $99 million budget for 1977 without levying the two-mill property tax to defray operating expenses. And although grants for buses over the past year have nearly doubled the amount of federal grants received for public transit since 1970, RTD is understandably cautious about the future:

> "...The history of federal involvement in transit in the Denver Region over the past five years has been mercurial at best: from early encouragement of ambitious long-term transit planning, to the selection of Denver for an advanced rapid transit demonstration project, to protracted requirements for the analysis of transit alternatives, to the current emphasis on short-term bus improvements and advance acquisition of transit ways. It is hard to predict what changing attitudes tomorrow--or next year--may bring."(13)

BUS SYSTEM IMPROVEMENTS

RTD currently is concentrating on its bus system (Figure 9-2). Although buses have been lower priority than the quest for a rapid transit system, RTD nevertheless has made notable improvements in Denver area bus service. In the past five years transit ridership has doubled, to three percent overall and 13 percent of the CBD destined work trips. The seven transit organizations which formerly served the District have been integrated, with standard fares, consolidated support services, and coordinated routes and schedules. Some 17 express bus routes, 60 park and ride sites, and 10 miles of exclusive lanes have been implemented, and additional studies are underway. Nevertheless, RTD recognizes that a major effort in upgrading the bus system remains (13).

At present, RTD's bus fleet is comprised of 520 vehicles. RTD has begun accepting delivery of the first of 231 buses to be purchased during 1977 and 1978, approximately 165 of which will replace very old equipment in use mostly in the suburbs. Although some of the remaining new buses may be mothballed for a few years once all are in use, RTD will have an active fleet size of about 600 buses. In addition approximately 65 of the better conditioned old buses will be retained in a reserve fleet for possible recall to service in an energy emergency.

RTD currently is revising its bus routes to make the system easier to use, with the first restructuring implemented in the northeast quadrant of the region during the Spring of 1978.[1] A report prepared

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[1] In parallel with the restructured bus routes and schedules, major changes in fare policy also have been made. Peak period fares have been increased from $.35 to $.50 for regular service and from $.50 to $.75 for express service. (A proposal was being considered in April, 1978 to change the definition of the morning peak period from 7-9 a.m. to 6-9 a.m.). Off-peak fares, however, were eliminated entirely on a trial basis, effective February 1, 1978 (with one day in February on which peak period fares also were eliminated). Initial results of the off-peak free fare, as determined by RTD, show an average increase of 41% in weekday ridership, nearly all of which was on local routes. About 6% of regular bus users switched from peak to off-peak ridership, and 80% of the new riders formerly made comparable trips by auto (13).

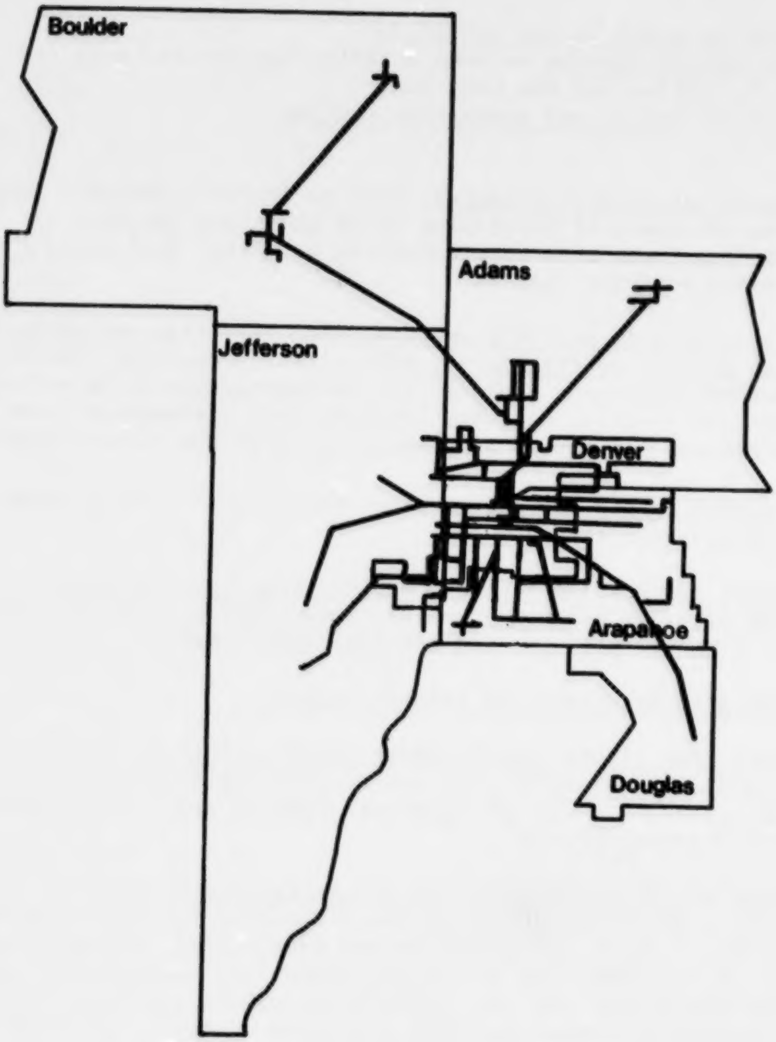
Boulder
Adams
Jefferson
Denver
Arapahoe
Douglas

FIGURE 9-2
Major Bus Routes

by R. H. Pratt and Associates is serving as the basis for the changes, although RTD staff members are adjusting specific recommendations to better accomodate local needs (15).

The basic principles being followed by RTD staff are as follows (15):

- Increase the speed on bus routes, by
  - using express service between activity centers and park and ride facilities and the CBD, and
  - increasing radial and cross-town service.
- Make local routes grid-oriented. This is intended not only to speed up the buses by minimizing turns and stops but also to make the bus route more comprehensible to users. Foci would be at major activity centers.
- Use circulators in activity centers, with very frequent service and with minimal or free fares. RTD currently operates "FreeRide" in downtown Denver and Boulder. The recommendation is to expand such service to other activity centers, with headways of less than 3 minutes for routes supplementing local and express routes.
- Match routes in the CBD and in other activity centers instead of having a bus turn around.
- Supplement bus routing changes, express service, and route matching with TSM measures such as transit malls, express lanes, vehicle actuated signals, and turning improvements.
- Minimize both transfers and transfer times.
- Use clock time rather than headways where service is infrequent (greater than 10 minutes), and use an even number of buses per hour (i.e., 12, 15, 20, and 60 minute spacing only). This makes the system easier to use.
- Use pulse schedule operation for community circulators: All buses for a given set of routes would start at the same time and point, "pulse out", and return to the same point; then all would set out at the same time again. All routes would operate on clock time and would have the same headway throughout the day. This would provide for transfers with a minimum of delay and would make it easy to remember service intervals. The routes would connect residential areas to attraction areas and would provide feeder service to both local and collector routes.

Desired minimum operating (timetable) speeds are as follows:

Type of Service	Minimum Speed (MPH)
Local	12
Express	25
Community Circulator	10
Activity Center Circulator	--

Local routes preferably should have no more than a 30 minute daytime headway, with a one-hour maximum. Express service, which is expected to remain primarily CBD-oriented through the period of interest, is provided during the peak periods with no less than three trips during a peak. Activity center circulators would have very short headways, especially during the peak; community circulator routes, on the other hand, are expected to have fairly low patronage and could operate on 30 - 60 minute headways throughout the day.

Pratt's analysis indicated that a 1987 fleet size of 900 buses was financially feasible at a total capital expenditure of $548 million and a cumulative transit operating cost of about $700 million, of which about 20% would be covered by farebox revenues (15). This assumes a bus fleet growth rate of 4.7% per year. The bus allocation was as follows:

- 569 buses (63%) on 17 radial and 11 crosstown local routes
- 182 express buses (20%) servicing 18 areas including 10 park and ride lots
- 63 buses in 18 circulator areas (activity centers and communities)
- 42 buses in intercity service, and 44 in Boulder/Longmont.

RTD's revised plan probably will include less local radial service and more express service than the Pratt report suggests. Also, Pratt recommends emphasizing frequent service in preference to extensive coverage; RTD staff members are in some disagreement over this, with some arguing that closer spacing than Pratt allows for is needed to maintain and attract ridership. The goals being aimed for, however, amount to an overall service improvement on the order of 20-25%. Ridership is projected to increase on the order of 10% (23).

In carrying out these service improvements, RTD is following an approach which supports the eventual establishment of a rapid transit system. Thus, short-term transit improvements will be progressively upgraded in those corridors where rapid transit alignments would go in the future.

OTHER TRANSIT ACTIVITIES

RTD currently is carrying out a number of additional projects and studies to improve existing service and to lay the foundation for eventual expansion. Several of these have potential implications for air quality.

Downtown Shuttle

A free downtown shuttle service known as FreeRide began in 1976, under the sponsorship of RTD and Downtown Denver, Inc. (DDI). The objective of the service is to reduce the number of intra-downtown auto trips and to encourage use of RTD's bus system. DDI provides an extensive advertising and promotion program in the form of in-kind services in support of the service. When FreeRide began, DDI agreed to provide RTD with the equivalent of $100,000 in advertising but that figure topped $200,000 within six months. Significant downtown ridership increases have resulted from the service. Comparing January-August ridership for 1977 and 1976, the increase was from 276,000 to 417,000 riders or a growth of 58%.

16th Street Mall

For several years, Downtown Denver, Inc., RTD, and the City and Country of Denver have been engaged in the planning of a CBD pedestrian/bus mall to be located on 16th Street between Broadway and Larimer (11 blocks long). Basic design and traffic engineering plans were completed early in 1978, and application has been made to UMTA to continue with more detailed design.

CBD express buses would terminate their trips at either end of the mall at two new offstreet stations, and small shuttle buses or trams would operate in both directions on 16th Street. The land for the two new terminals would be obtained by RTD with UMTA loan money, and these terminal areas are being designed so that they could be converted to stations on a fixed rail transit system should such a facility be constructed in the future.

The mall would require a large number of traffic changes in the CBD, including reversal of several one-way street pairs, conversion of some one-way streets to two-way operation, selected road widenings and realignments, and traffic signal re-timing. The project is expected to significantly enhance the attractiveness of both riding transit (further supplementing the free downtown circulator service) and walking along the spine of the CBD. The impact on express bus commuter patronage, however, must be considered uncertain since many current passengers will have to transfer from the express bus to the shuttle bus or tram to reach their destinations.

The idea of a downtown pedestrian/bus mall was initially proposed in 1974 by Downtown Denver, Inc. The design at that time, though, assumed funding by a special assessment on those properties which would benefit from the improvement. Consequently, the mall was opposed by Denver's three major retail establishments and most of the smaller merchants as well. In addition, while the concept of a mall was supported by the City's Planning Office, this support did not extend to the more powerful Public Works Department.

RTD has stated that they are prepared to fund the approximately $50 million project, even without the support of federal money from UMTA, since the project both demonstrates RTD's willingness to implement innovative transit projects and is compatible with future modification to a fixed rail system. Combined with the success of Denver's own 16th-17th St. bus lanes and Minneapolis's Nicollet Mall, support from both the City and retail merchants is now much more widespread than in 1974. (Only one of the City's major downtown stores has not been fully supportive of the concept.) Support for the mall is strong among the smaller shops since studies have shown these stores may benefit more from the mall than will the larger establishments.

The proposal recently stirred controversy when RTD's analysis showed that the mall could boost downtown auto traffic as a result of related traffic flow improvements. RTD concedes that air quality would not be directly affected by the mall (17).

Corridor Studies

RTD has initiated several studies in order to develop more detailed knowledge of both existing and projected population and employment conditions within the adopted primary corridors to be served by transit. The immediate objective is staged implementation of improved bus service within the designated corridors; the studies will examine alternative ways to operate buses to accommodate preferential treatments as well as determining requirements for more effective handling of auto travel and parking. At the same time, joint development, value capture and urban design possibilities are being considered. Advanced acquisition of right of way is a possibility.

The first study, conducted in cooperation with the City and Country Traffic Engineering Division, focused on the corridor extending 3.5 miles east from the Central Business District to Colorado Boulevard. The spine of this corridor is East Colfax Avenue, a two-way undivided commercial strip arterial. Parallel to Colfax are 5 one-way streets, 13th, 14th, 16th, 17th and 18th Avenues, which traverse residential neighborhoods inhabited by greater than average percentages of minority residents and transit dependent persons. The corridor carries heavy commuter traffic to and from the CBD in the peak periods and also serves as a major access route to Aurora and Stapleton International Airport. Several local, limited stop, and full express bus routes traverse the corridor, running along each of the 6 east-west arterials. The Phase I interim report prepared by Barton-Aschman Associates identifies several opportunities for improving bus levels of service, all aimed at increasing the attractiveness of transit and ridership potential in the corridor (18):

- Preferential treatments can signficiantly improve currently deficient bus schedule adherence.
- Round trip transit route times can be reduced by tightening layover schedule allocations, thereby permitting rescheduling and reduction of headways on some lines.
- Transit running times on Colfax Avenue can be significantly reduced by decreasing the number of bus stop locations.
- Preferential treatments for buses through congested sections of Colfax Avenue could potentially save 6 to 7 minutes in round trip travel time during the most congested period (between 9:00 AM and 3:00 PM). Due to heavy curbside activity and shopping traffic throughout the mid-day, there is greater congestion then than during peak periods. Hence, the potential for increased commuter ridership, though this measure may be somewhat more limited than normal.

Alternatives examined included use of 14th and 16th Avenues in addition to Colfax Avenue itself, with the possibility of splitting inbound and outbound service. Estimated construction costs are $5,048,800 (19,20).

The citizen participation effort indicated that preferential bus treatments were opposed by corridor business interests because some on-street parking spaces would have to be removed. In addition, the City of Denver's Public Works Department expressed reservations about putting preferential bus lanes on East Colfax; the DPW would prefer the use of parallel arterials if such treatments are to be implemented at all.

Because of neighborhood opposition, combined with RTD's desire not to generate bad publicity that could influence their higher priority CBD mall, a decision was made in mid-1977 not to proceed with further design studies in the East Colfax corridor.

Similar studies of multimodal traffic improvements and joint development opportunities have been performed in three other corridors: South Santa Fe, Buchtel, and Central Valley. While oriented primarily to the preferential treatment of buses, these studies also have examined joint usage with carpools, the potential of commuter rail operations, and future adaptability to rail transit operations. The Santa Fe Corridor study concluded that commuter rail operations would result in an annual deficit of $780,000., compared to an estimated deficit of $240,000-$270,000 for an express bus operation carrying the same number of passengers at the same fare (21,22).

TRANSIT CONTRIBUTIONS TO AIR QUALITY IMPROVEMENTS

RTD has exercised both financial and political autonomy to a notable degree in developing its transit plans and programs. In carrying out the mandate to implement a transit system for the Denver area, the agency has been reluctant to modify its priorities to accommodate other objectives or to change its procedures to make them consistent with those of CDH or DRCOG. This independent attitude occasionally has disgruntled other agencies. In general, however, relations between RTD and the organizations responsible for transportation/air quality plan implementation--APCC, APCD, and EPA--have been smooth. There is some feeling that RTD has not moved as quickly on bus improvements as it might have, and there was a short-lived disagreement over the appropriate number of bus lanes.[1] But, at its own pace perhaps, RTD has conducted the studies called for in the TCP; and although VMT reduction per se has not been the driving force behind bus planning, RTD clearly is improving transit in the Denver area.

RTD's position is that its whole program is compatible with air quality improvement objectives, and that minor variations in timing and details will not make much difference because transit's air quality impact is rather small. As one RTD staff member put it, "Just about anything we do successfully will have a positive, though perhaps marginal, effect on air quality." The one exception is locating park and ride lots, where CO "hotspot" problems can develop; for example, a proposed facility contiguous to a major highway in Littleton was delayed because of APCD concern that net CO concentration would be unacceptable. Although RTD fears that locations further away from radial highways will not be attractive (with travel time to the facility offsetting any potential savings from express service), it acceded to APCD's request for further study. On most other matters, the agencies agree that RTD's transit improvements are a step in the right direction, and in general, they leave one another alone.

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[1] EPA, in particular, wanted many more bus lanes than RTD believed were justified either by demand levels or under reasonable bus allocations.

To obtain an analytical estimate of the potential air quality impacts resulting from bus service improvements of the sort proposed for Denver, the following policies were examined using the capabilities described in Appendix C:

- reduce bus headways by 25% areawide.
- double the frequency on all CBD-destined routes.
- improve the frequency of existing express routes to the CBD in accordance with the Pratt recommendations (15).
- reduce in-vehicle travel time by 20% on all CBD-destined routes.

Either of the first two policies is feasible with the number of buses being obtained as a result of the recent UMTA grants. The express route frequency improvements recommended by Pratt also are within RTD's ability to implement. The fourth policy, which could be achieved by a combination of preferential treatment and increased express service, is consistent with the measures now in operation in the Lincoln-Broadway corridor and those evaluated in studies of the East Colfax and Sante Fe corridors.

Table 9-1 presents the impacts of a regionwide reduction in bus headways, i.e., an improvement in frequency of service, by 25%. This change results in a 20% increase in ridership above transit's current 3 percent regional mode share. The increase translates into less than half a percent reduction in VMT, fuel consumption and emissions, however.

TABLE 9-1

VMT Reduction Potential of 25% Reduction in Bus Headways

% Change from Base, Areawide

	WORK TRIP MODE SPLIT				Work Trip VMT (Miles/Day)	Work Trip Fuel Cons. (Gal/Day)	WORK TRIP AUTO EMISSIONS (kg/day)		
	DRIVE ALONE	SHARED RIDE	TRANSIT	VAN-POOL			HC	CO	NO_X
BASE (AVG/TRIP)	0.78	0.19	0.03	0.0	12.80	1.05	0.13	1.85	0.05
Policy: **Headways Reduced by 25% (areawide)**	-0.5	-1.1	21.0		-0.4	-0.4	-0.4	-0.4	-0.3

In Table 9-2, the results of the three CBD-oriented policy analyses are shown. Doubling the frequency on CBD routes increases bus ridership to the CBD by 40 percent and reduces VMT to the CBD by 3.6 percent. The regionwide effects are a 21 percent transit ridership increase and a VMT reduction on the order of half a percent.[1] Improving the frequency on existing CBD express routes as recommended by Pratt also increases transit mode split, by 12.5 percent, with a somewhat lower regionwide VMT reduction of about 0.2 percent. Reducing in-vehicle travel time by 20% on all CBD routes was less effective, raising the number of bus commuters by 6 percent, with a very small regionwide VMT reduction. Such a result is consistent with numerous studies showing that waiting time (determined by headways) is more onerous than in-vehicle time.

The analyses show that while the transit improvements being considered can stimulate quite large increases in transit mode share, these increases do not necessarily produce large reductions in VMT or emissions. In a low density city like Denver where the current transit mode share is moderate to low, large percent improvements represent rather modest numbers of persons changing modes. Thus, the analysis supports RTD's contention that transit improvements generally improve air quality, though not in a major way, and suggests that such improvements should be implemented as one component of a long term transportation management program which provides alternatives to auto use.

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[1] CBD transit trips are about 60 percent of total transit trips.

TABLE 9-2

VMT Reduction Potential of CBD-Oriented Transit Policies

% Change from Base (CBD Work Trips)

	WORK TRIP MODE SPLIT				Work Trip VMT (Miles/Day)	Work Trip Fuel Cons. (Gal/Day)	WORK TRIP AUTO EMISSIONS (kg/day)		
	DRIVE ALONE	SHARED RIDE	TRAN-SIT	VAN-POOL			HC	CO	NO_X
BASE (AVG/TRIP)	0.60	0.27	0.13	-	11.83	1.01	0.12	1.73	0.04
Policy:									
• Double frequency on all routes to CBD	-4.6	-7.8	40.0	-	-3.6	-4.1	-4.2	-4.5	-3.4
• Improved frequency on existing CBD express routes	-1.9	-2.1	12.5	-	-1.8	-1.9	-1.9	-1.9	-1.8
• Reduce in-vehicle travel time by 20% on all routes to CBD	-0.8	-1.2	6.0	-	-0.8	-0.8	-0.8	-0.9	-0.8

SUMMARY OF FINDINGS

1) The quest for a new rail transit system has been the central theme of transit planning in Denver, and other public transportation concerns have been of lower priority. Objectives have shifted from personal rapid transit, to automated rail transit, to light rail transit, and now to a downtown pedestrian/bus mall integrated with transfer stations at either end.

2) There is some feeling consequently that RTD has not moved as quickly on bus related improvements as it might have, and there was a short-lived disagreement over the appropriate number of bus lanes. But RTD has, at its own pace perhaps, conducted the studies called for, although VMT reduction *per se* has not been the driving force behind bus planning.

3) Nevertheless, RTD has made meaningful strides in improving its bus service as called for in Denver's air quality plans. Peak period preferential bus lanes have been implemented, a program of transit park and ride facilities is under construction, monthly transit passes are available, and an areawide offpeak free fare demonstration has been initiated. In addition, bus routes are being restructured, new buses are being obtained, and free downtown circulators are provided at all times in both Denver and Boulder.

4) RTD, however, has largely gone its own way in developing transit plans and programs, exercising both financial and political autonomy to a notable degree. In carrying out its mandate to implement a transit system for the Denver area, RTD has been reluctant to modify its priorities to accommodate other objectives or to change its procedures to make them consistent with those of other agencies.

5) RTD's position is that its whole program is compatible with the objective of improved air quality, but that minor variations in timing and details will not make much difference because transit's air quality impact is rather small. Each of the four bus improvement policies examined - areawide headway reduction, doubled bus frequency to the CBD, improved CBD express bus frequency, and reduced in-vehicle travel time to the CBD - reduced VMT and provided air quality improvements. Regionwide increases in transit utilization of up to 20% are forecast with these policies, with corresponding VMT reductions to approximately .4%. Transit gains to the CBD increased by a maximum of 40%. RTD estimates that its current route restructuring program will increase ridership on the order of 10% within each sector where new service concepts are implemented. Since transit mode share is relatively small, even very large percentage gains produce only moderate VMT and emissions reductions.

6) Compared to other transportation/air quality measures examined, transit improvements are the most expensive, with implementation costs running hundreds of millions of dollars. For example, it is estimated that the current regionwide bus system improvements will result in a long term capital expenditure of $548 million. The CBD mall cost estimate is $47.5 million.

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(3) 38 F.R. 214 - Wednesday, November 7, 1973, pp. 30818-30825.

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(17) "RTD Plan Could Boost Auto Traffic: Mall/Transitway Won't Curb Pollution," *Rocky Mountain News*, February 5, 1978.

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CHAPTER 10

ECONOMIC IMPACTS

INTERRELATION OF TRANSPORTATION AND SPATIAL ACTIVITY PATTERNS

This chapter examines how air quality transportation measures described in previous chapters may interact with various economic, demographic, and technological forces to change the spatial distribution of economic activity in the Denver region. These economic impacts do not typically comprise explicit objectives of air quality planning. Rather, they are indirect, unintended consequences of policies adopted to achieve other objectives.

The most important such impacts probably arise from changes in the relative accessibility of different parts of the metropolitan area. Such changes are particularly likely in the Central Business District. In most metropolitan areas, the CBD is one of the very few places with sufficient density of economic activity to attract the number of trips required for extensive transit service. If the region-wide transportation/air quality plan seeks to promote a shift from auto to transit usage, trips to the CBD may be among the few that are candidates for this strategy. Also, because of the density of its development, the CBD generally suffers from greater traffic-related air quality problems than other parts of the metropolitan region. Therefore, in addition to policies designed to reduce area-wide auto emissions, transportation/air quality plans typically include special measures to change the pattern of travel within the CBD.

Traffic control measures directed towards the CBD thus can be grouped into two broad classes: those that restrict automobile travel or reduce its attractiveness; and those that increase the appeal of alternative modes. The first group includes policies that reduce the number of parking spaces, make them more expensive or eliminate them altogether. More direct limitations on auto travel are embodied in auto restricted zones that restrict or even ban the automobile from specified portions of the CBD. All of these measures can be supplemented with the provision of plentiful, low cost parking on the fringes of the CBD, but even so, they all increase either the time or the money costs of drivers with downtown destinations.

The second class of policies, which increase the attractiveness of modes other than the auto, are often planned for implementation at the same time as those restricting auto use, so that attractive alternatives are available. Measures in this class include:

- Improvements in public transit to the CBD from other parts of the metropolitan area. Improvements may consist of lower fares, increased frequency, and new routes. Greater speed may be achieved as a consequence of express service, preferential lanes, reduced downtown congestion and the ability of transit vehicles to operate in the auto restricted zone.
- Incentives for the formation of carpools, such as preferential lanes and parking facilities.
- Introduction of shuttle bus service in the downtown area. A principal objective of shuttle service is to provide convenient access to the center from peripheral parking facilities, so as to minimize the loss of access for drivers who formerly used less remote lots.

In contrast to measures that restrict the use of the auto, these policies seek to improve downtown access or to mitigate the loss of access that the other measures would otherwise impose.

In addition to creating incentives that discourage driving in the CBD, transportation/air quality plans also may seek to improve the general attractiveness, environment, and convenience of activities in the area. Some of these improvements are expected to result as byproducts of the policies already described. Reductions in pollution and congestion from reduced auto use, for example, can improve both the downtown environment and the convenience of intra-CBD travel, which does not typically involve an automobile. Added convenience is also provided by shuttle buses that serve many downtown destinations. In addition, plans for auto restricted zones can include substantial investment in store renovation and pedestrian amenities.

In addition to their intended results, all of these measures may change the competitive position of the CBD compared with other locations in the metropolitan region. Although they are unplanned, these secondary economic impacts are not unimportant. If they are adverse to the CBD, they can impose economic hardship, producing a loss of retail sales, a contraction of job opportunities, vacancies in downtown buildings, and declines in the value of property as economic activity shifts from the CBD to other parts of the region. Fear of such losses lies behind the common opposition of the downtown business community to transportation controls and associated policies.

Besides their distributional consequences, adverse economic impacts may impede the achievement of public policy goals. Nearly all American cities are seeking ways to stem decline in the downtown in order to preserve its contribution to the municipal tax base and its employment opportunities, among other reasons. A strong downtown also can contribute to the achievement of air quality objectives by providing a source of jobs and shopping opportunities for which transit access is a viable alternative to the automobile. Both the distributional impacts on downtown business and the consequences for public policy make it essential that the direction and size of economic impacts be understood.

An understanding of the economic effects of transportation/air quality measures must be grounded in an understanding of the growth rate and the spatial distribution dynamics of population and employment. Such population and employment data are important for projecting future travel patterns, the nature of air quality patterns, and the performance of proposed remedies. Therefore, the next section examines population and employment trends and forecasts for the Denver region. The study then focuses on the sensitivity of retail sales in the Denver CBD to changes in its competitive position relative to other locations in the metropolitan region, with special reference to changes brought about by transportation control policies. The five sources of evidence include:

- An examination of historical trends in downtown retail sales and identification of their determinants.
- Interviews with leading retailers in downtown Denver to discover their views on the area's competitive strengths and weaknesses.
- Case studies of the response of retail sales to transportation policies in the CBD's of other cities.
- A regression model that measures the sensitivity of sales in alternative retail centers to differences in market characteristics, including transportation access to potential customers.
- A disaggregate logit model of individual shopping trips that shows how the choice of shopping destinations responds to changes in transportation policy.

The final part of the chapter evaluates the impact of air quality transportation measures on the CBD's ability to compete for office activity with other parts of the metropolitan area. The analysis relies principally on evidence from recent historical trends and interviews with representatives of financial institutions and other heavy users of office space.

POPULATION AND EMPLOYMENT PROJECTIONS

The Denver region has experienced rapid growth in population and economic development over the past decade. This growth has made forecasting future trends difficult because it is hard to say whether or how long such rapid growth might continue. The state of the art in population and employment forecasting is still developing, and especially when rapid growth and in-migration is occurring, there are great uncertainties in projections.

The technical difficulties in developing population and employment projections are further complicated by the politics of growth and development. As is the case in many regions, there is competition among jurisdictions within the Denver area for large shares of the economic growth. Many of the jurisdictions have established land use and development plans which reflect their desire for growth and their optimism that they can attract it. Their population and employment forecasts similarly reflect this optimism. Because areas with substantial commercial and industrial development often are better able to provide generous services without requiring high property tax rates, local governments may find it politically desirable to project high future growth. Furthermore, such projections tend to be favored by real estate owners and developers who thereby have greater flexibility in the opportunities for land use than they would under more restrictive or conservative planning.

In Denver, several population and forecasts exist, and they differ substantially from one another. These forecasts are examined below.

Population Forecasts

DRCOG population forecasts exist for both the four-county region of Adams, Arapahoe, Jefferson, and Denver Counties and the five-county region that includes Boulder County.[1] The major forecasts of population for the year 2000 are identified in Figure 10-1, each of which is for the five-county region. The slopes of the growth lines depict percentage rates of growth. Brief descriptions of the derivation of the forecasts appear below:

- Office of Business and Economic Research Service (OBERS). This forecast is based on the allocation of a national population forecast to different regions of the country. Its principal feature is the assumption that migration will reduce regional economic disparities and therefore, weaken further migration from one region to another in the future. Since much of Denver's population growth has been caused by positive net migration, the OBERS assumptions lead to a relatively low estimate of future population.

- Colorado Land Use Commission. This projection, one of several alternatives originally prepared by DRCOG, assumes that the excess of births over deaths among existing residents will lead to a rate of net natural increase of 8.5/1000 residents in each year until 2000. This rate corresponds to the actual rate in 1972. Net migration during 1975-1980 will fall from the abnormally high levels of the early 70's to the level prevailing in the 1960's (15,700 annually), and, during 1980-2000 will approximate the average 1940-1970 level (15,100 per year).

- DRCOG Adopted Forecast. Assumptions are similar to those that are behind the forecast of the Colorado Land Use Commission, except that 1975-80 net migration is assumed to be 20,600 persons annually and the 1980-2000 levels is set at 22,000. These migration levels are between the abnormal levels of 1970-75 and the historic levels of the preceding 30 years.

- Denver Research Institute. Assumptions are similar to those that lie behind the forecast of the Colorado Land Use Commission and DRCOG, except that still higher estimates of future net migration are assumed. The result is a forecast range of 2,350,000 to 3,000,000, the midpoint of which is 2,675,000.

- Colorado Division of Planning (County Total and City Total). The Division of Planning made separate surveys of county officials and municipal officials in 1974 to determine local population forecasts. The sum of the individual county forecasts and the sum of individual city forecasts yielded identical totals of 2.9 million.

- Metropolitan Denver Water Study Committee. A deliberately high forecast to provide a margin of safety in planning for adequate future provision of water.

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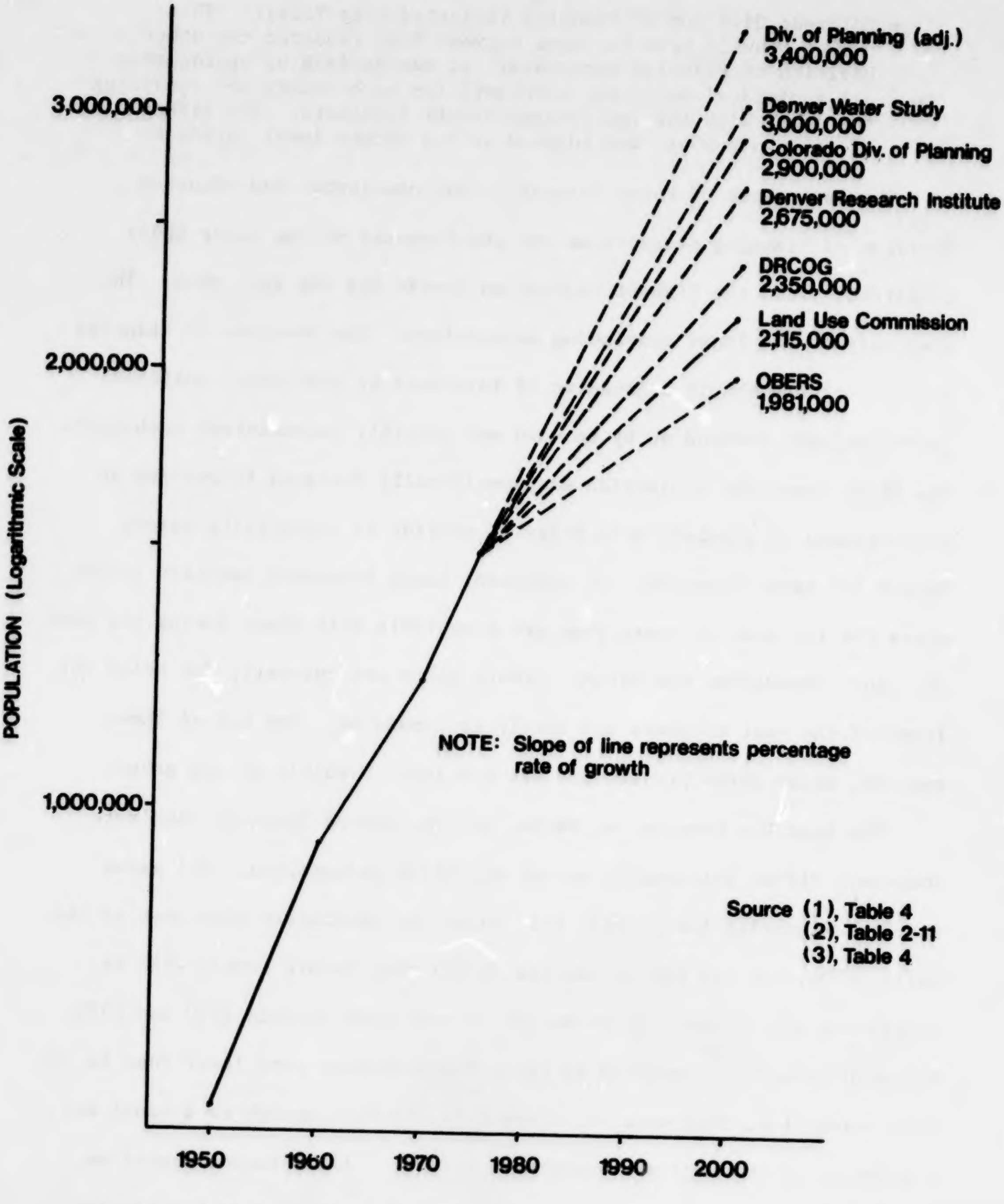
[1] Factual information on forecasts of future populations is drawn from Reference (1).



NOTE: Slope of line represents percentage rate of growth

Source (1), Table 4
(2), Table 2-11
(3), Table 4

FIGURE 10-1

Population Forecasts for the Five County Denver Region

- Colorado Division of Planning (Adjusted City Total). This number results from the same surveys that produced the other Division of Planning forecasts. It was derived by aggregating all individual municipal forecasts for each county and comparing the total with the independent county forecasts. The higher of the two numbers was adopted as the county level forecast.

The last three of these forecasts--the unadjusted and adjusted Division of Planning projections and the forecast of the Water Study Committee--yield the highest population levels for the year 2000. They also rely on the least convincing methodology. The Division of Planning projections are simply aggregates of forecasts by individual political jurisdictions, arrived at by unknown and possibly inconsistent techniques. The Water Committee projection was specifically designed to provide an overestimate of population in order to provide an engineering safety factor for water planning. In addition, these forecasts envision growth rates for the next 25 years that are comparable with those during the past 25. But, throughout the nation, growth rates are currently far below the level of the past 25 years and likely to remain so. For all of these reasons, these three projections are the least credible of the group.

The Land Use Commission, DRCOG, and the Denver Research Institute forecasts differ principally on net migration assumptions. All agree that net migration levels will fall below the abnormally high ones of the early 1970s, but all assume (unlike OBERS) that future levels will be consistent with those that prevailed at some time between 1940 and 1970. Although levels of migration in these three decades were lower than in the early seventies, they were still consistently high enough to account for a majority of the region's population growth.[1] All forecasts based on historic migration levels therefore project a future population greater than that foreseen by OBERS.

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[1] See Reference (1), Table 3.

Actual levels of migration since 1975 have fallen between those assumed in the Land Use Commission and the DRCOG forecasts. This early evidence, however scanty, suggests that the Council of Governments projection presents an appropriate upper bound for the future population of the region and, consequently, for the air quality problems that this population will generate.[1] This conclusion is reinforced by the recognition that the DRCOG forecast assumes a natural increase in the region at the rate prevailing in 1972; however, in Denver as in the rest of the nation, the rate of natural increase has dropped sharply since then and is likely to remain at a low level into the future. If the OBERS forecast, which assumes a gradual end to the net migration that has kept regional population growing at more than twice the national rate for nearly half a century, is accepted as a lower bound for future population, while the DRCOG forecast is considered an upper bound, the range of uncertainty for future population is narrowed considerably. The DRCOG forecast is less than 20% greater than the OBERS projection, compared with an initial range of forecasts in which the greatest was more than 70% larger than the smallest. Both forecasts envision future regional rates of growth that are substantially slower than those of the recent past.

The Council of Governments forecast allocates the regional population to neighborhoods within the City of Denver and to planning districts called urban service areas in the suburbs.[2] The allocation procedure begins with local forecasts produced by municipal and county agencies and adjusts these to be consistent with the regional population projection. The process of adjustment includes the following steps:

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[1] Actual 1975-1976 migration as reported in Reference (2) was 16,600.

[2] The boundaries of Denver have been assumed constant at their 1975 limits, and urban service areas also have been held constant over the planning period from 1975-2000 (2).

- Neighborhoods in the City of Denver and urban service areas in the suburbs have been divided into two groups: those that have been declining or growing only modestly, and those where growth has been rapid.
- For areas with little or no growth, local forecasts of future population have been incorporated into the DRCOG forecast.
- For rapidly growing Denver neighborhoods, the local forecast has been accepted for the years up to 1980. After 1980, their average rate of growth has been reduced from locally projected levels to a rate equal to the region-wide rate (1.8% annually). Growth in Denver neighborhoods that exceed the region-wide rate is considered unlikely by the Council of Governments.
- Growth rates in rapidly growing suburban areas also have been reduced, although they remain the highest in the metropolitan region. The locally projected change in population has been summed up for all these areas and the share of the total increase attributable to each area has been computed. The total has then been reduced so that, when added to the change in population projected for other parts of the region, the sum is equal to the change projected by DRCOG for the entire region. This new total has been allocated to individual high growth service areas according to the shares computed from local projections.

The resulting allocation of population between city and suburbs for the four-county Denver region is shown in Figure 10-2, showing that the bulk of the region's growth is projected to occur in the suburbs. However, the projections show modest growth for the City of Denver, in contrast to the declines in the historical data. There are two reasons for the change. First, the projections are based on Denver's 1975 boundaries, which include more than 40 square miles (more than 50%) of land than the 1960 definitions used in the historical analysis.[1] Since this added area is more like the suburbs than the core of the city, it will experience growth that can offset decline in the core. Second, the

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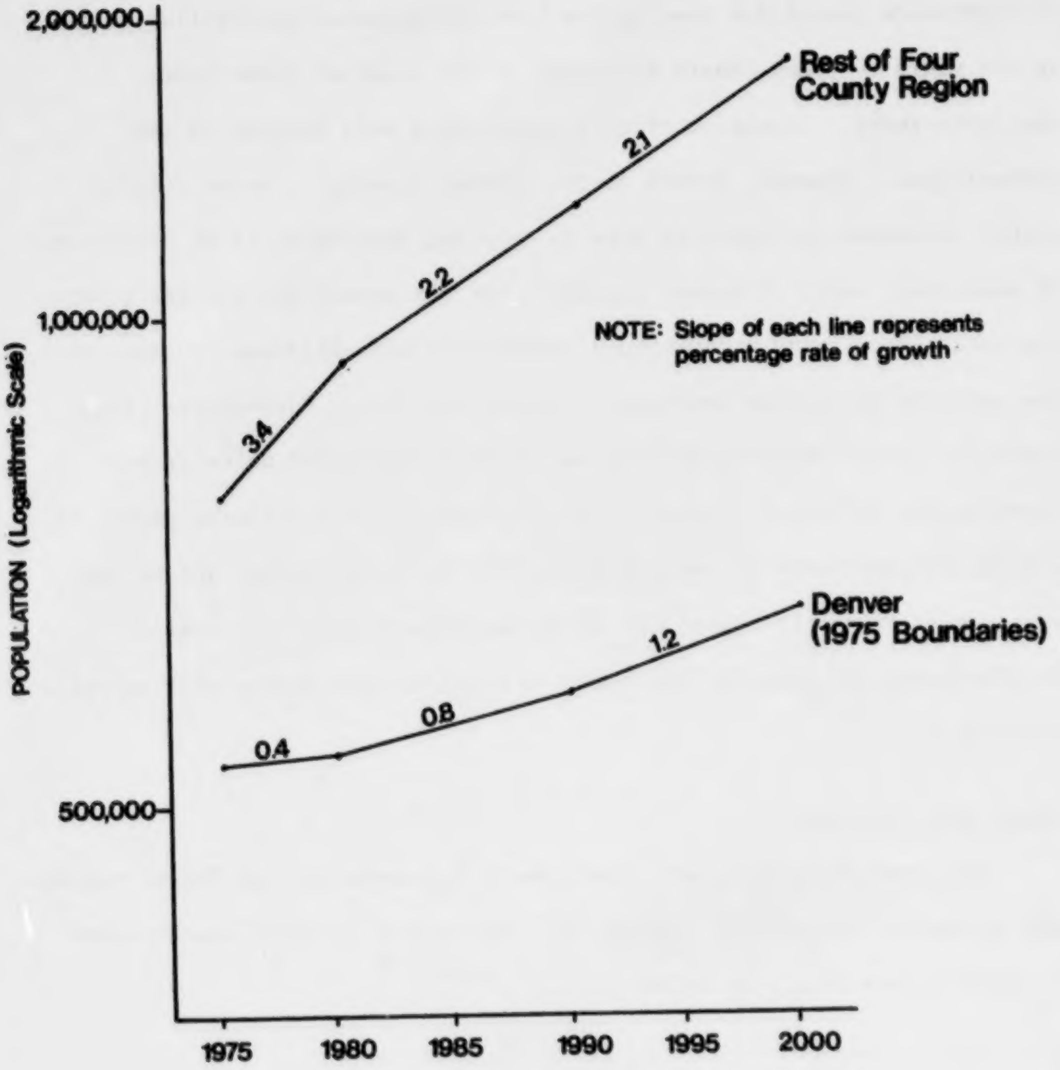
[1] Unpublished Annexation Statistics, Denver Planning Office.



Source (2),
Table 2-11

FIGURE 10-2

Allocation of DRCOG Population Forecasts to the City and Suburbs of the Denver Region forecast embodies an end to decline and its replacement by growth in the core itself, as out-migration is replaced by in-migration. An end to decline may be a reasonable expectation. For example, in a few central neighborhoods demand for housing has been strengthened substantially in recent years by young people attracted to the kinds of older homes available there. Expansion of this trend could halt decline in the central area. However, growth in the central population would require either increases in household size in existing housing units or provision of additional units at higher density. The new demand for central housing has been concentrated among single individuals and childless couples, who are unlikely to produce increases in household size. Furthermore, they appear to occupy existing housing rather than subdivided units or new construction at higher density.[1] The expectation of population growth in central neighborhoods is therefore unlikely to be fulfilled, and to the extent that projected growth for Denver depends on growth in central neighborhoods, it probably overstates the growth that Denver will actually experience.

Employment Forecasts

Like population forecasts, employment forecasts for the Denver region are available from several sources (3), Table 10-1.[2] Brief descriptions of these forecasts appear below:

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[1] Information for this paragraph was gathered from interviews with planners and mortgage lenders in the Denver community.

[2] Because different forecasts use slightly different definitions of the Denver region, it is appropriate to focus on forecasted rates of growth from 1970-2000, rather than absolute levels of employment.

TABLE 10-1

Employment Forecasts for the Denver Region

SOURCE		ANNUAL AVERAGE GROWTH RATE, 1970 - 2000
OBERS[1]		2.0%
DRCOG[1]		2.4%
Colorado Division of Planning[2]	- low	1.1%
	- high	3.1%
System Management Contractor[3]	- low	2.3%
	- high	3.1%

Source: (3), Tables 6 and 14.

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[1] Five Counties - Adams, Arapahoe, Boulder, Denver, Jefferson

[2] Eight Counties - Adams, Arapahoe, Boulder, Clear Creek, Denver, Douglas, Gilpin, Jefferson

[3] Six Counties - Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson

- Office of Business and Economic Research Service. The OBERS employment forecast for the Denver region, like the comparable population forecast, was derived by allocating a national forecast to different regions of the country. The allocation was based in part on historical trends in the share of national output produced by each region and in part on an assumption of narrowing disparities in economic growth in different parts of the country. Since Denver's past growth has been more rapid than the national average, the assumption of convergence towards the average yields a relatively low regional rate of growth.

- DRCOG. This employment projection embodies a composite of several methods. First, the average yearly change in regional employment between 1958 and 1975 was projected forward to obtain a simple straight line forecast of future job levels. Then alternative projections were obtained with the shift-share method. Shift-share projections assume that the regional rate of growth in each economic sector depends upon the national rate of growth in employment, the difference between that sector's performance and the performance of total employment at the national level, and the disparity between national and regional rates of growth within each sector. The nature of these relationships was estimated from historical data for 1958-1975, and the shift-share results were used to adjust the timing of initially forecasted employment growth and to distribute it among economic sectors. Finally, the growth potential of each sector was examined individually, and the forecast was adjusted accordingly.

- Colorado Division of Planning. The State of Colorado has developed a model to forecast population and employment simultaneously. To produce the employment forecast, jobs are divided into three types. Growth in basic employment, which produces goods for national markets, is determined by the rate of growth of the national economy and the ability of Colorado to attract jobs from other regions. Household serving industries, which produce goods and services for the local population, grow when natural increase and net migration cause growth in the regional population. Regional business serving employment grows in step with local business performance. Using different assumptions concerning the growth of the national economy and the ability of Colorado to attract jobs from elsewhere, this model has produced forecasts of regional employment growth that range from 1.1% to 3.1% annually.

- System Management Contractor (SMC) for the Regional Transportation District. The SMC forecasts used U.S. Government projections of national employment growth and tested various plausible assumptions about the relationship between regional growth and national growth. The SMC forecasts ranged from 2.3% to 3.1% annual employment growth for the Denver region.

Both the Colorado Division of Planning and SMC forecasts embrace a range of alternatives so broad that the remaining uncertainty limits their usefulness. The OBERS and DRCOG employment projections bear roughly the same relationship to one another as their respective population forecasts and can be regarded as plausible upper and lower bounds on regional employment growth. The DRCOG forecast for employment in the year 2000 is about 20% greater than the OBERS forecast.

As with its population forecasts, the Council of Governments has allocated its employment forecast to detailed geographic areas within the region. The resulting assignment of employment to the CBD, rest of the city and suburbs of the four-county region is shown in Figure 10-3. The pattern of rapid growth in the suburbs, slower growth in the CBD, and still slower growth in the rest of the city is consistent with historically observed patterns. As with population projections, projected growth in the City of Denver may be somewhat more rapid than the historical information would suggest because the forecast is based on 1975 rather than 1960 boundaries.

Spatial Structure

The population and employment forecasts adopted by DRCOG embody a continuation of historical patterns in which rates of growth in suburban parts of the Denver region far exceed those in inner city neighborhoods. An understanding of these historical patterns aids in assessing the likelihood that they will continue in the future. In addition, the forces governing the location of economic activity must be grasped before the economic impacts of transportation controls on different parts of the metropolitan area can be properly assessed.[1]

Looking first at the decentralization of jobs, the shift from rail transportation with centrally located yards to truck transportation for

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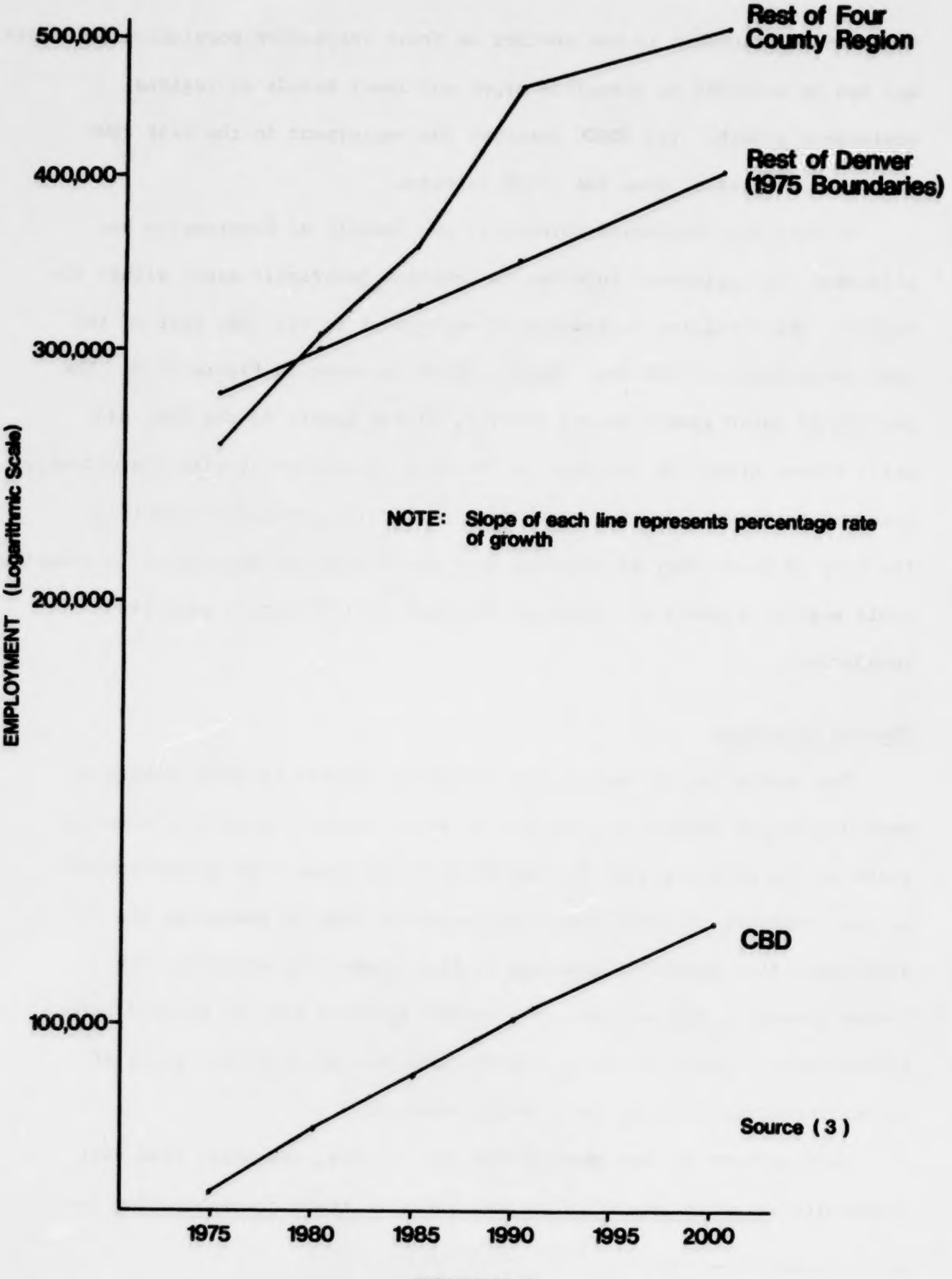
[1] The classic analysis of recent changes in the spatial structure of U.S. cities is Reference (4). Recent residential movements in the Denver region are discussed in Reference (5).



NOTE: Slope of each line represents percentage rate of growth

Source (3)

FIGURE 10-3

Allocation of DRCOG Employment Forecasts to Subareas of the Four County Region intercity shipments has conferred advantages on suburban sites with better access to highways than locations in the more congested city. At the same time, the relatively small quantity and high cost of land in the city has made it unattractive to firms whose technology requires large tracts for single story plants. As a result, in Denver as in most American cities, growth in manufacturing jobs has been strongly skewed towards sites outside the city with plentiful vacant land and good highway access.

Secondly, Denver's growing population and a demand for newer, larger homes at low density as incomes increased among local residents most easily could be met by construction on vacant land in the suburbs. Widespread auto ownership has meant that Denver area households can freely consider suburban locations with minimal concern for transit availability. Upper income families, who buy the newest, largest homes on the largest lots, are likely to be least satisfied with existing homes in the city and most likely to be attracted by vacant land available at reasonable prices in the suburbs.

Institutional factors also have encouraged people to choose the suburbs instead of the city. Because of the high income of their residents and the relatively low demand for social service expenditures, suburban communities often can afford to provide better schools than the city, making them especially attractive to families with children. The attraction of suburban schools recently has been enhanced for many families in the Denver region by dissatisfaction with court-ordered school busing programs undertaken in the City of Denver.

The rapid growth of population in the Denver suburbs has itself spurred job dispersal. Suburban workplaces have become the closest and most convenient sites for many of the region's workers. In addition, the growth of suburban communities has created large markets that are attractive to businesses serving local customers.

Some activities have been more resistant to decentralization than others. An example is the financial community, which remains quite firmly anchored in the CBD. In general, however, the forces that have promoted dispersal in the past remain strong today, and projections of suburban rates of growth that substantially exceed those in the city are justified.

In interviews, government and business representatives involved with the development of Denver have concurred in this assessment, noting that continued suburban development is dependent not only on the forces described above but on continued absence of restrictive land use controls and continued ability to provide essential utilities to newly developed areas. There is little likelihood that the Denver area will develop land use controls to redirect the pattern of regional development. Limits on new gas and water connections could restrict suburban growth. With respect to water, such restrictions are likely to be temporary responses to climatic aberrations and temporary shortages in water treatment facilities, rather than permanent constraints on development. With respect to gas, past restrictions have had little overall impact on suburban growth; and future energy supplies, future technology, and the future response of consumers and producers of housing are sufficiently uncertain to preclude any confidence in projecting their development effects.

RETAIL SALES IN DOWNTOWN DENVER

The economy of the Central Business District[1], Figure 10-4, is very specialized, with the vast majority of activity concentrated in the office and retail sectors. This concentration is evident from Table 10-2, which shows the distribution of non-residential floorspace in the CBD by categories of use. Between them, the office and retail sectors account for more than five-sixths of the space. In analyzing potential effects of transportation measures on the downtown economy, attention is focused on these two activities.

TABLE 10-2

Distribution of Non-Residential
Floorspace in the Denver CBD, 1975

Category of Use	Percent
Private and Government Office	64.0%
Retail, Restaurant, and Personal Service	19.7
Civic, Educational, Non-Profit Uses	8.2
Manufacturing and Wholesale Trade	5.7
Auto Dealers and Transportation Terminals	2.3
Total	100.0%

Source: (7), unpublished tabulation.

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[1] As is evident from Figure 10-4, there is some difference between the definition of the CBD employed by the U.S. Census and the one used by agencies in the Denver area. Since data from both Census and local sources are used in this report, the reader should note that they refer to slightly different areas. Because the bulk of CBD activity is concentrated in the area encompassed by both definitions, research findings are similar regardless of the definition adopted.

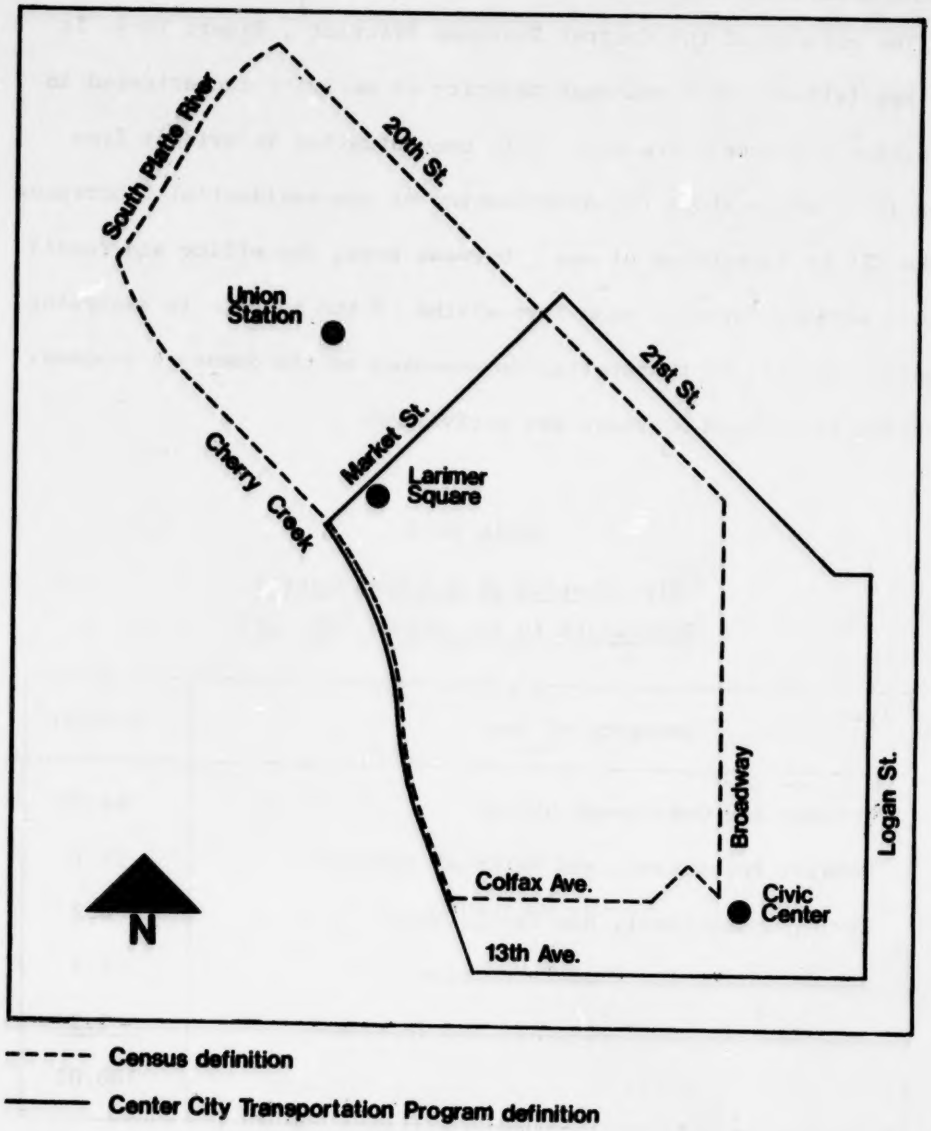
South Platte River
20th St.
Union Station
21st St.
Market St.
Larimer Square
Cherry Creek
Broadway
Logan St.
Colfax Ave.
Civic Center
13th Ave.
N
- - - - Census definition
—— Center City Transportation Program definition

FIGURE 10-4

Denver Central Business District

Sales Trends

In recent years, downtown Denver has suffered a steady decline in the real volume of retail sales, after correction for inflation (Figure 10-5).[1] The sources of this decline are easy to identify. Despite the rapid growth of the Denver region, there has been a steady decline in population in neighborhoods nearest the CBD, and the region's poorest residents, who have the least buying power, account for an increasing share of those remaining in these neighborhoods. The CBD also has suffered from increasingly intense competition with growing suburban shopping centers which are large enough to be effective substitutes for the Central Business District. Suburban consumers, whose automobiles give them access to shopping centers throughout the region, can enjoy the proximity, convenience, and informality of suburban centers with little or no sacrifice in the selection of goods available, compared with what is offered in the CBD.

Recent trends in downtown sales for different kinds of goods are shown in Figure 10-5. Sales are stated in constant dollars of 1967,

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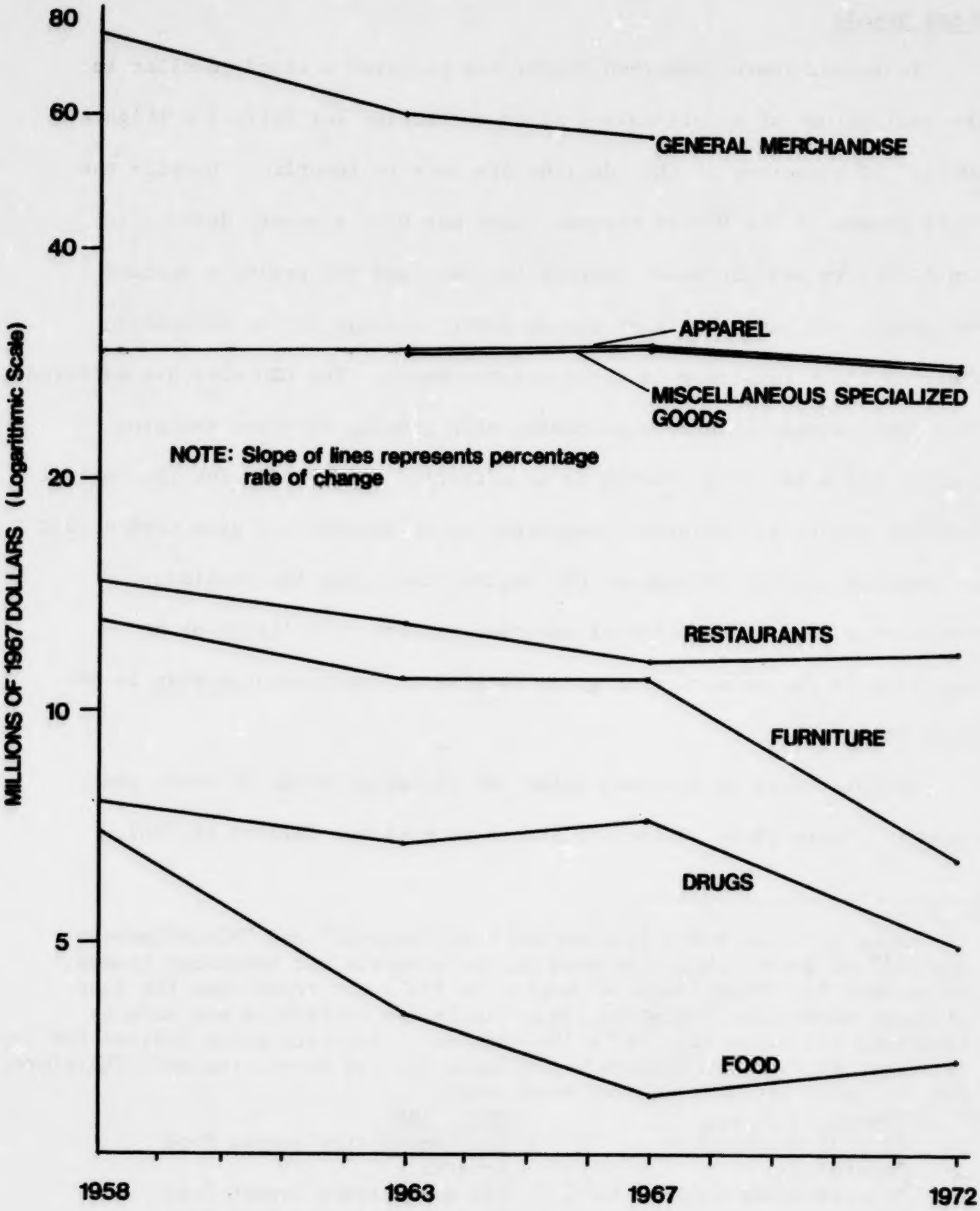
[1] In Figure 10-5 the trend line marked both "Apparel" and "Miscellaneous Specialized Goods" should be read as two separate but identical trends. Since data for "Miscellaneous" begins in 1963, the trend line for that class of goods also begins in 1963. Inflation correction was made by restating all sales figures in 1967 dollars. Separate price indices for different kinds of goods were unavailable for the Denver region. Therefore, the following national indices were used:

Commodity Groups	Price Index
General Merchandise	All Commodities except Food
Apparel	Apparel
Miscellaneous Goods	All Commodities except Food
Restaurants	Food Service away from Home
Furniture	House Furnishings
Drugs	Average of Drugs and Toilet Goods
Food	Food Service at Home

Source: Reference (7), Tables 123, 126, 127; Reference (8), Tables 117, 119, 120.



Source (9)

FIGURE 10-5

Recent Trends in CBD Retail Sales by Product Line with each commodity group deflated by the appropriate component of the consumer price index. The real volume of sales has declined for every group in the years examined. Comprehensive data are not available after 1972, but scattered information suggests that similar trends have characterized succeeding years. According to data from the Denver tax assessor's office, dollar sales of apparel, accessories, and furniture in seven CBD department stores rose 17.1 percent between 1973 and 1976, before adjustment for inflation. Since the price index for apparel rose 14.7 percent and the index for furnishings climbed 26.6 percent over that period, the assessor's figures suggest that the real volume of sales at best has remained level, and at worst has continued the pattern of decline evident in preceding years.[1]

Further insight into the retail economy of downtown Denver can be gained by looking at individual lines of sales in Figure 10-5 and Table 10-3.

TABLE 10-3

Retail Sales in the CBD, Constant Dollars of 1967, By Product Line

([1]1967 figures for general merchandise are the latest available)

Product Line	Average Annual Compounded Percentage Change	Period of Analysis	Percentage of SMSA Sales Accounted for by CBD (1972)
General Merchandise	-3.4%	1958-1967[1]	17.4%
Apparel	-0.2%	1958-1972	20.8%
Miscellaneous Specialized Goods	-0.9%	1963-1972	11.9%
Restaurants	-1.6%	1958-1972	6.3%
Furniture	-5.2%	1958-1972	3.8%
Drugs	-3.1%	1958-1972	5.0%
Food	-5.0%	1958-1972	0.6%

Source: (9)

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[1] Sales figures are from Reference (10). Price indices are from Reference (11) Tables 7A and 8A (December 1973), and Tables 3A and 4A (December 1976).

For both percentage declines in downtown sales and the share of metropolitan sales captured by downtown merchants, there are striking differences in the performance of different categories of commodities. The fastest rates of decline and the smallest shares of metropolitan sales are shown by food, furniture, and drugs. Much stronger performance has been registered by apparel, restaurants, and miscellaneous goods (including, for example, bookstores, record stores, gift shops).[1] The distinguishing feature of the stronger performers is their appeal to noon-hour shoppers. Were it not for the noon-time shopping of workers in nearby offices, the loss of downtown sales to suburban competition would have been much more severe.

The trends revealed in these statistics have been verified and updated in interviews with leading downtown merchants. These retailers have confirmed that downtown sales have grown more slowly than inflation in the years since those shown in Figure 10-5, so that the real volume of sales has continued a pattern of gradual erosion. A few stores are planning to close downtown outlets or to reduce their size in response to declining sales. The major exception to this pattern has been Larimer Square, a recently opened complex of restored historic buildings where the developer has controlled the kinds of shops, their architecture, and their hours to create a mix of complementary shopping opportunities. Throughout the 1970s, new stores have opened in Larimer Square, and sales per square foot in existing outlets have increased at an approximate annual rate of 12%, substantially faster than inflation over the same period. The atypical performance of Larimer Square can be attributed to a combination of unique characteristics: its historic interest, which has made it a popular tourist attraction; its selection of hours to cater to events in the nearby convention center; and the combination of a planned mix of stores, an attractive pedestrian environment, and cheap and plentiful parking in nearby lots cleared by urban renewal, all of which may enhance its ability to compete with suburban alternatives.

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[1] General merchandise, which includes department stores, shows a contradictory pattern, with a relatively rapid decline in real sales combined with a high fraction of SMSA sales. Part of the reason may be the absence of 1972 data. If, for example, the real volume of general merchandise sales, which was roughly level between 1963 and 1967, continued level until 1972, the 14-year rate of change would have been a considerably smaller rate of decline, -2.2%. Also, the fact that general merchandise is an aggregate of many different product lines makes the results difficult to interpret.

Other downtown merchants readily acknowledge substantial handicaps in competing with the suburbs. In their view, their most serious problem is the inconveninence and cost of downtown shopping for automobile drivers. Since most suburban shoppers are closer to at least one suburban center than to the CBD, the length of the trip places downtown merchants at an immediate disadvantage. In addition, parking near suburban stores is convenient and usually free (or cheap); in the CBD convenient spaces are limited and relatively expensive, and low-cost parking is relatively inaccessible. Thus, shoppers who drive downtown must spend more time and pay more than suburban shoppers. Merchants in the CBD also suggest that the congestion of downtown traffic and the confusing pattern of intersections and one-way streets intimidates the shopper who would otherwise drive to the CBD at irregular intervals. Finally, many shoppers seem to feel that downtown shopping requires more formal dress than suburban alternatives, a perception that further detracts from its convenience.

The cost and inconvenience of shopping downtown could be at least partially offset if stores in the CBD offered variety, quality, or price advantages not found in suburban alternatives. In Denver, however, such advantages are minimal. Department store executives with both suburban and downtown outlets confirmed the lack of downtown superiority in most product lines. In fact, for many goods in many stores the reverse has become common. Small shops offering specialized products unavailable elsewhere in the region are also uncommon in the Denver CBD. As a result, retail sales in the CBD have relied increasingly on transit dependent customers and on noon-hour shopping by nearby workers. Even in the largest department stores, officials estimate that more than half their business now depends on noon-hour shoppers; in other downtown stores, the noon-hour share is closer to 70%.

Merchant Perceptions

Merchant attitudes towards air quality transportation measures have been shaped by the characteristics of the markets they serve. A principal concern is the continued availability of convenient parking, which is seen as essential to attract those shoppers with automobiles whose patronage has not already been eroded away by suburban competition. Retailers believe that there is no adequate substitute for parking facilities very close to their stores. If parking is removed to peripheral locations, the prospect of walking even a few blocks with packages or in inclement weather is seen as sufficient to create a severe competitive disadvantage relative to suburban centers. Even shuttle buses providing frequent door-to-door service from peripheral lots to the retail center are regarded by merchants as a poor alternative to nearby parking.

The merchants cite shoppers' current parking patterns as evidence for their position. In the Skyline Urban Renewal Area at the periphery of the CBD, there are many low cost parking spaces just four to eight blocks from the heart of the retail center, and many of them are served by convenient shuttle buses departing every six minutes. Although no data have been collected, there is general consensus that few shoppers take advantage of these lots, preferring instead more expensive spaces that are more convenient.[1]

Parking expense itself is another concern of downtown retailers. They believe that parking charges already are high enough to discourage drivers from casual trips to the CBD, and that only a major shopping excursion can justify downtown rates, especially those in convenient locations. However, they believe that parking policies that sought to reduce rush hour congestion by raising all day rates, while maintaining or reducing current short term charges, could be beneficial in their retail impact.

Existing levels of public transit service, which favor the CBD relative to other shopping centers, have given downtown merchants a competitive advantage in attracting shoppers without access to cars. Because transit dependent shoppers account for an important fraction of sales in at least a number of downtown stores, maintenance of existing service is strongly supported by the downtown retail community. Improved transit service, however, is not expected to attract those who currently drive, because transit is an unattractive alternative for shoppers with bundles.

Both existing shuttle buses, which provide free circulator service throughout the CBD, and the proposed RTD 16th Street mall are supported by most affected stores, though with varying degrees of enthusiasm. By eliminating traffic and providing pedestrian amenities, the mall might become more attractive for noon-hour trips and, perhaps, even might compete more effectively with the planned environment of suburban centers, especially if combined with a well-planned, complementary mix of stores. Reservations arise over fears of a lengthy construction interval, which could cause inconvenience and a loss of business that may never be regained, and opposition to any increase in CBD taxes to finance the project. The success of Larimer Square, which embodies many of the features planned for the 16th Street mall, suggests the potential of the mall concept, though the evidence is clouded by Larimer Square's special status as a historic tourist attraction.

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[1] Some supporting evidence is available from the 1970 Center City Transportation Project. Surveys for this project reported the fraction of parkers with downtown destinations during the peak parking period who chose remote parking spaces outside the CBD. (In general, such spaces would be even more remote than the Skyline spaces referred to in the text.) For workers, the fraction was 21.7%; for shoppers the fraction was only 6.3%. (Reference 13)

IMPACTS ON RETAIL SALES

Empirical Evidence

Both the historical performance of retail sales in the Denver CBD and the attitudes of downtown merchants suggest that downtown sales are very vulnerable to even small competitive disadvantages vis-a-vis suburban retail centers. To provide some quantitative measure of this sensitivity, case studies for other cities were examined and, in the following subsections, results from two economic models of the Denver retail sector are reported.

Some suggestive insights into the sensitivity of sales to competitive disadvantage can be gained from literature dealing with sales taxes. Several quantitative estimates of the loss of sales in communities with tax rates above their neighbors' are available. Two time series studies for New York City and a cross section study of 173 cities in 1963 are remarkably consistent in predicting a loss in sales of 6% to 10% in response to a sales tax rate rise of one percentage point. This loss in total sales represents a very great sensitivity to cost differentials among retail centers (4).[1]

Several case studies of the response of sales to transportation changes are available. In 1970, the City of San Francisco enacted a tax of 25% on all parking spaces, except those for residential users, hotel parking, and metered spaces. Nineteen months later, the rate was lowered to 10 percent. Independent evaluation studies, attempting to assess the effects of this tax on retail sales, found that the 25 percent parking price increase caused a 2 to 6 percent decline in the number of cars parked for shopping and a 30 percent decline in total demand for parking services, a combination of the number of cars and the duration of occupancy (13). However, declines in the demand for parking need not impact retail sales if they are offset by changes of mode, increased purchases per trip, or concentration of shopping into visits of shorter duration. Therefore, direct evidence was sought on the response of retail sales, but little was found to support an inference of adverse retail impacts. For all stores in the City of San Francisco, the dollar volume of sales remained level both after the initial imposition of the tax and its subsequent reduction.

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[1] The cost of a taxed item is equal to $(P + tP)$, where P is its nominal price and t is the tax rate. If $P=\$1$ and $t=.06$, a one percentage point increase in the tax rate yields $.01/1.06=.0094\approx1\%$ increase in cost.

However, as was recognized in the study, this evidence is weak. There is insufficient data to control for other forces, such as inflation and general business conditions, that may have masked the impact of the parking tax. In addition, data that encompass all of San Francisco are dominated by locations where free parking makes parking taxes irrelevant. To meet the second of these criticisms, the study presented figures on the volume of sales in San Francisco department stores which tend to be concentrated in the central locations most heavily impacted by the tax. In these stores, sales fell in the nine months after the tax, recovered to record levels, and fell again after the tax was reduced, leading to the conclusion of no long run effects from the tax. These results, however, also suffer from a lack of correction for the influences of other forces, such as general business conditions.

The Pittsburgh Parking Strike of 1972 provides case material for the study of reductions in parking availability. For the first three days in August, 1972, a strike by parking attendants closed all but 800 of the 25,400 spaces in the CBD. About 3,700 of 4,600 spaces on the fringe of the CBD and 300 to 500 usually illegal spaces on the street remained open. Retail sales in the CBD dropped by 6 to 8 percent and these declines were concentrated in quality stores heavily patronized by auto drivers (12). Losses of sales for restaurants and entertainment facilities ranged from 10 to 70 percent. Although the limited duration of the strike makes it likely that other determinants of sales remained constant over the period, it also limits the usefulness of the data for long run inferences.

Since 1975, the City of Singapore, to reduce auto traffic, has required a special license for all autos in the CBD between 7:30 and 10:15 A.M. and has raised parking charges throughout the day. A series of interviews prepared for the World Bank sought to ascertain the impact of these actions in downtown retail sales (14). Merchants agreed that the auto license had little effect, since shopping takes place outside the hours that it is effective. They regarded parking charges, however, as a factor in their loss of sales to suburban competitors. The high price of parking, in their view, both discouraged driving to shop downtown and encouraged short trips that yielded smaller purchases. Buses were regarded as crowded and unpleasant for shoppers with bundles and, hence, unsatisfactory as substitutes for automobiles.

There is by now a large body of experience with auto restricted zones in both the United States and Europe, as summarized in Tables 10-4 and 10-5. All of these zones ban the use of automobiles on one or more streets in the central retail district. Many have combined the ban with the provision of public transit within the zone and investment in pedestrian amenities and store renovation. The effect on sales of auto restricted zones, as reported in the tables, has generally been positive, although controls for other forces that may have affected sales are generally lacking in these data. These positive effects on sales might

TABLE 10-4

Impacts of European ARZ's

Source (15)

ARZ Effects Europe	MERCHANT'S ATTITUDES Before Construction	MERCHANT'S ATTITUDES After Construction	RETAIL SALES During Construction	RETAIL SALES After Construction	PEDESTRIAN VOLUMES	NEW CONSTRUCTION	SOURCES
BESANÇON, FRANCE 1974- Center City	n.a.	+ Merchants very pleased.	+ increase	+ increase		n.a.	OECD Proceedings
BOLOGNA, ITALY 1972- Center City	▬ Opposition; Dissatisfaction.	+ Strong support.	n.a.	n.a.		n.a.	OECD Proceedings
COLOGNE, WEST GERMANY 1959- Hohe Str, Schildergasse, etc.	▬ All opposed.	+ Strong support.	n.a.	+ 25-35%		+ Major reconstruction and rehab of historic area, oriented to tourism.	SOM Study GLC Study Tour
COPENHAGEN, DENMARK 1962- Stroget, Fiolstraede, etc.	▬ Mostly opposed.	+ Almost all in favor.	n.a.	+ 25-40%	+ 35-45%	Change in character of retail toward specialty, youth and torist orientation.	SOM Study GLC Study Tour OECD "Streets for People"
DUSSELDORF, WEST GERMANY 1957- Schadow Strasse, etc.	▬ All opposed.	+ All in favor.	n.a.	+ 40%	+ 60%	n.a.	SOM Study GLC Study Tour
ESSEN, WEST GERMANY 1945- Limbecker Str, Kettwiger Str, etc.	▬ Fierce opposition.	+ Strong support.	▬ initial decline	+ 15-30%		+ Major post-war reconstruction. Large new commercial projects on edge of downtown built and in construction.	SOM Study GLC Study Tour OECD "Streets for People"
GOTHENBURG, SWEDEN 1962- Center City, Kungsgatan, etc.	n.a.	+ Predominantly positive.	▬ loss	0		+ Major new in town center ('69-'74) shifted business activity. Residential reconversion on East side.	SOM Study GLC Study Tour OECD "Streets for People"
LEEDS, ENGLAND 1970- Bond St., Kirkgate, etc.	n.a.	+ Majority in favor.	n.a.	+ 20%		n.a.	SOM Study GLC Study Tour
MUNICH, WEST GERMANY 1971- Neuhauser Str, Kaufinger Str, etc.	n.a.	+ 92% of merchants approve.	n.a.	+ 20-40%	+ up to 200% on peak days.	+ Major new underground shopping area built. Extensive building rehab & reuse.	GLC Study Tour OECD Proceedings
NOTTINGHAM, ENGLAND 1973- Center City	▬ Initial opposition.	+ Strong support.	n.a.	n.a.	+ 10%	+ 30% increase in retail floor space in two major new centers. Extensive rehab.	OECD Proceedings
UPPSALA, SWEDEN 1972- Center City	▬ Strong opposition.	+ Favorable.	n.a.	▬ 0.1-5.0%		n.a.	OECD Proceedings
VIENNA, AUSTRIA 1971- Karntner Strasse, Graben, etc.	n.a.	+ Very favorable.	n.a.	+ 25-50%		n.a.	SOM Study GLC Study Tour OECD "Streets for People"

1. GLC Study Tour:
   Greater London Council
   Pedestrianized Streets
   GLC, London. 1973.
2. OECD Proceedings:
   Organisation for Economic Cooperation and Development
   Better Towns With Less Traffic
   OECD Conference Proceedings, Paris. 1975.
3. OECD "Streets for People":
   Organisation for Economic Cooperation and Development
   Streets for People
   OECD, Paris. 1974.
4. SOM Study:
   Skidmore, Owings, and Merrill
   Survey of American and European Auto-Free Zones. 1975.

TABLE 10-5

Impacts of U.S. ARZ's

Source (15)

ARZ Effects U.S.A.	MERCHANT'S ATTITUDES Before Construction	MERCHANT'S ATTITUDES After Construction	RETAIL SALES During Construction	RETAIL SALES After Construction	PEDESTRIAN VOLUMES	NEW CONSTRUCTION	SOURCES
ALLENTOWN, PA. Hamilton Mall 1973	n.a.	n.a.	n.a.	n.a.		+ Extensive new development and renovation downtown.	Fulton Arcade Report
ATCHISON, KANS. 1963	n.a.	n.a.	n.a.	+ 25%		+ $4 million.	SOM Study Barton-Aschman Report "Building Downtown Malls"
BURBANK, CA. Golden Mall 1968	− Strong opposition.	+ Almost all in favor.	+ improved	+ 22%		+ Little new construction; lowest vacancy rate since 1939.	SOM Study Pittas Study Barton-Aschman Report
DANVILLE, ILL. 1967	+ Merchants main force behind mall.	+ Almost all in favor.	0 no loss	+ 10-19%		+ Remodelling, storefront improvements, expansions.	SOM Study . Pittas Study "Building Downtown Malls"
FRESNO, CA. Fulton Mall 1964	+ Merchants main force behind mall.	+ Almost all in favor.	− some loss	+ 25% (+ 43% first 2 yrs)	+ 60%	+ $41 million. Some banks & hotels replacing retail.	SOM Study Pittas Study "Building Downtown Malls"
HONOLULU, HA. Fort & Hotel St. 1969	n.a.	+ Almost all in favor.	− 5-10%	+ 7-20%		+ New retail space added.	SOM Study Pittas Study Barton-Aschman Report
KALAMAZOO, MICH. Burdick Mall 1959	n.a.	n.a.	n.a.	+ 15%	+ 40%	+ $16 million. 84% of stores remodelled.	Barton-Aschman Report "Building Downtown Malls"
LOUISVILLE, KY. River City Mall 1973	+ Businessmen played major role in planning.	n.a.	n.a.	+ 15-25%		+ 2.5 million sq. ft. of new construction.	Fulton Arcade Report
MIAMI BEACH, FL. Lincoln Rd. Mall 1960	n.a.	n.a.	n.a.	+ 10-25%	+ 50%	n.a.	Barton-Aschman Report "Building Downtown Malls"
MINNEAPOLIS, MINN. Nicollet Mall 1968	+ Businessmen initiated mall proposal.	+ Great support.	+ gains up to 65%	+ 14-30%		+ $250 million directly adjacent or within ½ block.	SOM Study Pittas Study Barton-Aschman Report
OAKLAND, CA. Washington St. 1961	− Merchants opposed.	− Apathetic.	− some loss	+ up first few years, then level.		− Area slated for renewal. 3 blocks cleared; no new construction.	SOM Study Pittas Study
POMONA, CA. Pomona Mall 1962	+ Merchants main force behind mall.	+ Optimism waned, but returning.	− 10%	+ 16%	+ 73%	+ $7.7 million. Small stores closing, dept. stores expanding.	Pittas Study Barton-Aschman Report "Building Downtown Malls"
PROVIDENCE, R.I. Westminster Mall 1965	n.a.	+ Many in favor.	0 no loss	− 1.5% (- 20% rest of city.)		n.a.	SOM Study Pittas Study "Building Downtown Malls"
RIVERSIDE, CA. Main St. Mall 1966	+ Mostly in favor.	+ Almost all in favor.	− some loss	0 no losses (rest of city had losses)		+ Office and bank construction planned.	SOM Study Pittas Study
SALISBURY, MD. Downtown Plaza 1968	+ Merchants main force behind mall.	+ 100% happy.	0 no loss	+ up every year.		+ New businesses attracted.	Pittas Study Barton-Aschman Report
WASHINGTON, D.C. F St. Mall 1966	+ Most in favor.	+ Most in favor.	n.a.	+ 4.8% (- 5.4% rest of city.)	+ 23%	n.a.	Pittas Study HUD Study (1968)

1. SOM Study:
   Skidmore, Ownings, and Merrill
   Survey of American and European Auto-Free Zones. 1975.

2. Pittas Study:
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be construed as demonstrating the ability of transit service and investment in amenities to substitute for auto access. However, all of the U.S. auto-free zones described in the tables have been confined to a single street, and auto access has been maintained on surrounding streets. The zones' positive impact on sales therefore may be a measure of their ability to complement rather than to substitute for good auto access. European auto restricted zones have been larger, but caution should be exercised in transferring their experience because of potentially different attitudes towards auto and transit travel between Europeans and Americans.

Aggregate Retail Sales Model[1]

The evidence from the case studies along with the attitudes of Denver merchants identifies cheap and convenient access as a key determinant of retail sales. Much of this evidence, however, is anecdotal and imprecise. Two separate, but complementary, modelling methodologies were used to provide independent quantitative estimates of potential impacts of transportation control measures on downtown Denver's retail center. The two models serve as checks on one another and on the more impressionistic evidence.

In the aggregate model, the principal concern is the relationship between sales and market accessibility to households. Total retail employment and total retail sales have been measured for 153 zones in the Denver region.[2] The access of retail stores in any zone i to potential customers living in zone j is defined as the number of households in j divided by a measure of the travel time between the two zones. The greater the number of households in any zone, the greater its potential to generate business; but the longer the trip from that zone to a store, the smaller the probability that the store will capture that business.

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[1] A more complete technical introduction to this model, as well as of the disaggregate model, is provided in Appendix E. A full technical description is provided in Reference (16).

[2] These zones originally were defined for the application of the EMPIRIC activity allocation model.

The accessibility of stores in zone i to all households in the region is just the sum of their access to households in each zone. Mathematically, accessibility of stores in zone i (A_i) is defined as

$$A_i = \sum_{j=1}^{N} H_j \cdot f(t_{ij})$$

where N is the total number of zones, H_j is the number of households in zone j, t_{ij} is the travel time between i and j, and $f(t_{ij})$ is the impedance function that determines the impact of travel time on the decision to make a trip. Since stores in zone i are in competition with stores in all other zones in the region, their competitive position depends not only on their accessibility to potential customers but also on the access of competitors to this market. Therefore, it is assumed that retail sales are determined by competitive accessibility - the access to customers of stores in zone i, divided by the average of access measures for all competitive zones.

A key issue in air quality transportation planning is the ability of transit access to substitute for access by automobiles in attracting customers. To test for this substitutability, the model includes separate measures for auto access and transit access, each defined by the procedure just outlined. The transit access of stores in one zone to customers in another differs from auto access if travel times differ for the two modes.

The potential of households to generate retail sales depends not only on their number and their proximity but also on their level of income. For each retail zone, the income level of surrounding households is measured by the proportion of households in that zone with incomes in the lowest 15 percent of the region's income distribution. This measure of income allows an estimate of the negative impact on retail sales if nearby markets are dominated by low-income households.

Especially in the CBD, the importance of noon-hour shopping cannot be ignored. Since noon-hour trips are typically made only by white collar workers, the number of service, government, finance, insurance, and real estate workers in the zone is used as a means of determining the magnitude of this component of retail activity.

All of these relationships can be summarized in the following expression for retail sales:

$$S_i^* = g(C_i, T_i, Y_i, W_i),$$

where S_i^* is the dollar volume of retail sales in zone i, C_i is the competitive access of stores in i to customers travelling by car; T_i is their competitive transit access; Y_i is the proportion of zone i's residents with incomes in the lowest 15% of the regional income distribution; and W_i represents the number of white collar workers in i. Because the volume of retail sales and the number of white collar workers may vary arbitrarily with differences in the area encompassed by different zones, both are expressed in quantities per zone acre.

The expression for sales developed above assumes full adjustment to the current determinants of demand. To satisfy this assumption, stores must be expanded in areas where access to households has increased and reduced in scale where access has declined. Households, in turn, must adjust shopping patterns in favor of more accessible centers and those where growth in size has created greater shopping opportunities. In fact, however, such adjustments take many years. New stores are not opened immediately, nor existing ones closed, in response to changes in demand. Households have shopping habits acquired in the past. As a result, current patterns of retail sales may lag behind those predicted by the retail sales equation. These lags can be incorporated by assuming that only part of the adjustment to current determinants of demand takes place during any period of time; current sales are somewhere between what they were in the past and what they will be when full adjustment has occurred. Formally,

$$S_i^t = (S_i^*/S_i^{t-1})^\beta \cdot S_i^{t-1}$$

where S_i^t is current sales; S_i^* is fully adjusted sales; S_i^{t-1} is sales in the past; β represents the speed of adjustment. If β is .4, any change in the determinants of demand which leads fully adjusted sales to be 10% above those in the past period will cause sales to rise 4% in the current period. Forty percent of the ultimate change from the past period sales will take place in the current period.

The model has been estimated by regression analysis with 1960 and 1970 data originally assembled for the Denver EMPIRIC Activity allocation model. Since retail sales are not available from this source, they have been estimated from EMPIRIC employment data by using Census information on sales per employee to convert employment figures to sales.[1]

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[1] Sales per employee were computed separately for the CBD and for the rest of the region using data from the Census of Retailing. Data from 1963 were used to convert 1960 EMPIRIC employment figures and data from 1967 were used to convert the 1970 EMPIRIC data. Correction factors for the CBD were applied to zones in the CBD, and factors for the rest of the region were applied to all other zones. The methodology is described in greater detail in Appendix E and in Reference (16).

Representative sensitivity analysis results are presented in Table 10-6, generally confirming the impressionistic information reported earlier. When travel time by car rises 10%, retail sales decline by an estimated 10% after all adjustments have taken place. Although examination of percentage changes is useful, policies affecting downtown accessibility can be represented more accurately by changes in the number of minutes required to travel to the ultimate destination. A two and a half minute addition to this time is estimated to depress sales by 17.5%, and a five minute increase will lead to a 32.7% decline in sales. Because shopping trips are relatively short, even modest absolute increments to time represent significant percentage increases and significant reductions in accessibility. The model suggests, however, that adjustment of sales to changes in access is quite slow, with only 41.5% of the ultimate occurring the first decade. Finally, changes in transit time are forecast to have no significant affect on sales, so that improvements in transit access are not effective substitutes for decreases in auto access.

TABLE 10-6

Aggregate Retail Sales Model Results

One Way Change in Auto Time	One Way Change in Transit Time	Long Run Change in Retail Sales (Full Adjustment)	Proportion of Full Adjustment Taking Place in First Decade After Change in Level of Service
+10%	-	-10%	41.5%
+2.5 minutes	-	-17.5%	41.5%
+5.0 minutes	-	-32.7%	41.5%
-	Any Change	0.0%	-

Disaggregate Model of Retail Sales

The second analytical approach to measuring the retail impacts of transportation measures relies on the use of logit techniques to estimate the probability that shoppers choose one retail center rather than another. In contrast to the aggregate model, this approach explicitly models individual shopping trips, rather than relating aggregate sales in a zone to aggregate market characteristics. The model forecasts the number of home-based shopping trips by auto and transit from each of 274 Denver area traffic zones to shopping destinations in each of the zones. The number of trips from one zone to another and the choice of mode depend upon the following characteristics:[1]

- The number of households in the origin zone, their income, family size, and auto availability. These characteristics determine the number of potential trip makers, their propensity to make shopping trips, and their ability to travel by car if they choose.
- The density of retail activity in the origin zone. If there are many shopping opportunities at high density within walking distance of home, there is less need to make shopping trips by auto or transit.
- The density of retail employment and the number of retail employees in the destination zone, a measure of the density and scale of shopping opportunities. These opportunities determine the attractiveness of alternative destinations.
- The travel time and travel costs of trips between the two zones.

In addition to home-based trips, noon-hour work-based shopping is forecast for zones in the CBD, using similar techniques, as a function of the number of CBD workers, the number of shopping opportunities, and the time and cost of intra-CBD trips by foot, public transit, and automobile. Originally calibrated for Los Angeles, the work-based shopping model predicts that one-third of all workers in the Denver CBD make such trips each day, a number consistent with empirical findings for other CBDs throughout the country.

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[1] As with the travel demand results reported elsewhere in this report, model parameters were originally estimated for the San Francisco metropolitan area and have been adjusted to Denver so as to correctly forecast the total number and modal split for shopping trips reported by the 1971 Denver home interview survey. Denver data for 1970-71 have been used throughout this part of the analysis.

The forecasting technique requires that both models be used to predict a base number of shopping trips to each zone in the metropolitan region, given existing levels of service on the transportation system. Then, the levels of transportation service are adjusted to reflect impacts of an air quality measure on travellers to the CBD. A second iteration forecasts a new number of trips and a new spatial distribution, reflecting these changes to the transportation system.

For purposes of this analysis, it is assumed that, in every zone, changes in the number of shopping trips to the zone cause proportional changes in the level of retail sales,[1] and, eventually, in the level of retail employment. Adjustments in employment mean adjustments in the size of the retail center and in the attractiveness of the shopping opportunities that it offers. A third iteration is therefore required to forecast a pattern of trips consistent with these new levels of shopping attractiveness. Because each new pattern of trips causes further changes in retail activity and shopping attractiveness, a series of further adjustments must also be predicted.

As an illustrative example, assume the following structure for these adjustments. Let ΔT^i be the change in trips to zone i because of a change in the level of service; let A_1^i be a further adjustment in trips because shopping opportunities have changed in response to ΔT^i; let A_2^i be a further adjustment because opportunities have further changed in response to A_1^i; and so forth. If

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[1] As stated in the discussion of the San Francisco parking tax, there is some uncertainty in the reasonableness of this assumption.

$$\alpha = \frac{A_1^i}{\Delta T^i},$$

where ΔT^i and A_1^i have been estimated by the model system, the full series of adjustments is assumed to follow the form

$$\Delta T^i + A_1^i + A_2^i + A_3^i \ldots\ldots =$$

$$\Delta T^i + \alpha\Delta T^i + \alpha A_1^i + \alpha A_2^i + \ldots =$$

$$\Delta T^i + \alpha\Delta T^i + \alpha^2\Delta T^i + \alpha^3\Delta T^i + \ldots =$$

$$\frac{\Delta T^i}{1-\alpha}$$

Results of this process are shown in Table 10-7 for policies similar to those tested with the aggregate model. Several characteristics of these results merit discussion. The total change in shopping demand in response to any transportation policy is the sum of two components: first, a change in the number of trips in direct response to the change in the level of service; and second, a strong reinforcing spiral of demand in response to changes in the size and attractiveness of the retail center. For example, a 2½ minute addition to walk time for parkers leads directly to a loss in trips of 5.5%. However, the chain of further adjustments by shoppers who find the smaller retail center less attractive leads to a total loss of 29.8% of the initial number of trips.

The disaggregate model predicts a greater response in shopping demand than does the aggregate model, a 29.8% decline in trips compared to the aggregate model prediction of a 17.5% loss in sales. This disparity

TABLE 10-7

Disaggregate Retail Sales Model Results

Denver CBD

Policy	Original No. of Shopping Trips	Response to Change in Level of Service	% of Original Shopping Trips	Response to Change in Size of Retail Center	% of Original Shopping Trips	New No. of Shopping Trips	% of Original Trips
+2.5 minutes one-way walk time for parkers	53,000	-2917	-5.5	-12,869	-24.3	37,214	70.2
+5.0 minutes one-way walk time for parkers	53,000	-5259	-9.9	-17,355	-32.7	30,386	57.3
-5.0 minutes one-way wait time for transit riders[1]	53,000	+ 425	+0.8	+ 2,271	+ 4.3	55,696	105.1

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[1] For noon-hour bus trips within the CBD, for which average wait times are currently estimated at 5 minutes, a reduction of 2½ minutes has been assumed.

suggests that the chain of reductions in demand that reinforce the initial shrinkage of the retail center may be overestimated by the disaggregate model. In other respects the disaggregate results reinforce inferences already made from both the aggregate model and other evidence reported in this chapter. Reductions in accessibility appear to result in significant losses in downtown sales; increases in transit access have a very minor impact.[1]

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[1] The disaggregate model also was used to examine a policy that raises long term parking rates to discourage parking by workers and cuts short term rates in half to fill the spaces with shoppers. Estimated effects of this policy are a direct increase of 24.1% in shopping trips and a much larger gain in additional trips by shoppers attracted to the expanded retail center. However, this great sensitivity to costs (which is, for example, much greater than the 9.9% loss in trips directly attributable to an extra 5 minutes of walk time for parkers) seems implausibly high. It suggests a greater willingness on the part of shoppers to trade accessibility for monetary savings than Denver merchants believe to be the case. Nevertheless, it indicates that lower parking costs for shoppers could have a beneficial effect on CBD retail activity.

THE OFFICE ECONOMY IN DOWNTOWN DENVER

A successful downtown office complex is sustained by forces very different from those that govern the performance of retail sales. Where the downtown retail center is just one of many competing centers in the metropolitan region, the office complex in the CBD is, by contrast, unique. It offers by far the region's largest concentration of office space in which all activities are easily accessible to one another. Whereas a retail center requires accessibility to customers, the occupants of offices in the CBD are there because they require a degree of accessibility to one another which is available nowhere else in the metropolitan area.

A glance at the kind of office activities that predominate in the CBD reinforces this observation. The CBD is foremost a financial center and a legal center. Both finance and law are characterized by large numbers of complex negotiations and transactions that bring together many different people in face-to-face meetings where information is generated and agreements are reached. These meetings require such frequent interaction of bankers, other financial managers, accountants, investment advisors, securities brokers, and lawyers that vast amounts of time would be lost if they had to travel far to meet one another. Because of the complexity of the issues, telephone conversations and written memoranda are usually poor substitutes for face to face discussion. As a result, in cities throughout the country, finance, law, and associated services have clustered more compactly in the center of town than any other branch of economic activity and have been more resistant to decentralization.[1]

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[1] For a more detailed treatment of these ideas, see Reference (4).

The Denver region, most recently, has become a center for energy firms, and these activities have the same preference for central locations as finance and law. Their reasons are similar. According to interviews in the Denver business community, energy executives seem to require detailed and continuously updated information on business conditions of a kind which is available only from continual interaction with one another.

In all of these industries, rapid growth in the Denver region and continued preference for concentration in the CBD have led to rapid expansion of downtown office activity, in contrast to stagnation and decline in the retail sector.[1] Table 10-8 shows growth of employment in the core from 1962-1977; because office and retail activity has continued to dominate in this area and because all available evidence suggests decline in the retail sector, all of these gains can be attributed with confidence to growth in office work. In fact, to the extent that declines in retail employment have occurred, the change in total jobs understates the increase in office jobs.

Growth in downtown office space has been even more dramatic than growth in jobs (Table 10-9). The 1962 data, which cover the office and retail core, is not exactly comparable with data for later years, which include the entire CBD; and some of the growth in office space may result from wider geographic coverage rather than construction of additional facilities. However, the amount of CBD office activity that takes place outside the core is small enough that one can reasonably state that office space in the core nearly doubled.

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[1] Because of lack of detail in available statistics and often inconsistent definitions in different data sources, there is only rudimentary quantitative evidence on these trends. A 1963 source identified a part of the CBD as the office and retail core (Figure 10-6), containing nearly all downtown activity in these two sectors and very little else. In 1962, 68 percent of all employees in the core worked in offices and 24 percent in retail stores (17).

TABLE 10-8

Employment in the Office and Retail Core of the CBD

Year	Total Employment	Annual Average Compounded Percentage Change
1962	48,469	
1970	54,670	+1.5%
1977	73,900	+4.3%

Sources: (17, 12, 19)

TABLE 10-9

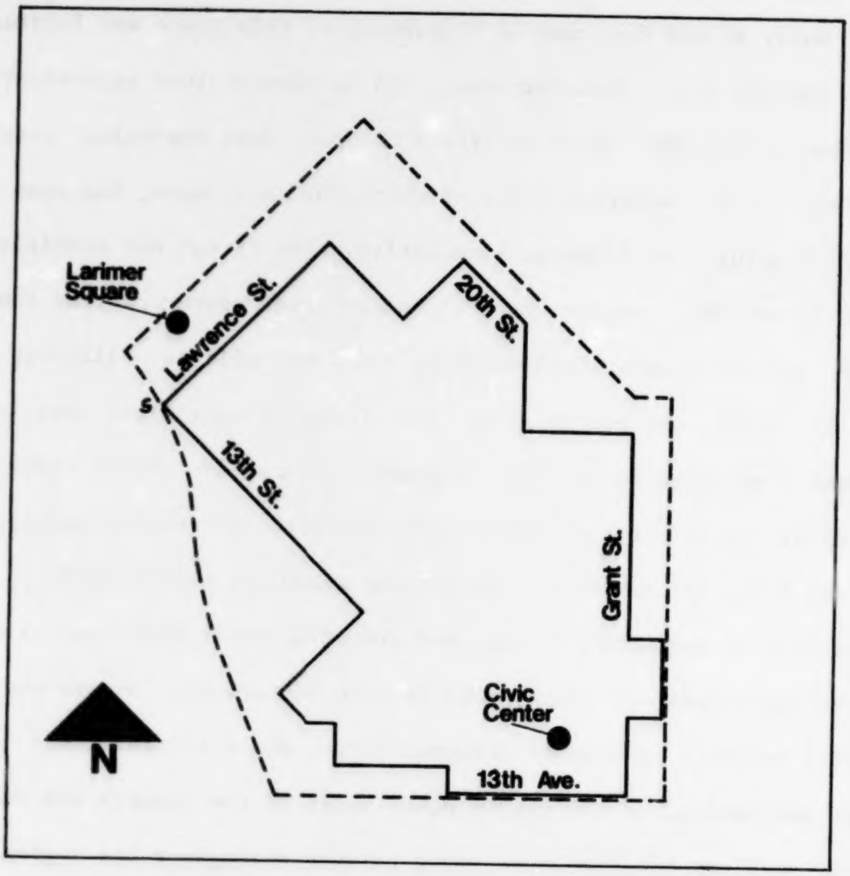
Office Space in the CBD

Year	Square Feet of Office Space (Private and Government)
1962	8,100,000[1]
1970	10,100,000
1975	13,200,000
1977	16,100,000[2]

[1] Office and Retail Core only. All other figures are for the entire CBD.

[2] The 1977 number was derived by assuming that all of the increase in total floorspace in the CBD between 1975 and 1977 represented increased office space.

Sources: 1962 (17)
1970 (12)
1975 and 1977 (20)


Larimer Square
Lawrence St.
20th St.
s
13th St.
Grant St.
Civic Center
13th Ave.
N

—— Retail Core definition

- - - - Center City Transportation Program definition

FIGURE 10-6

Office and Retail Core of Denver Central Business District

During the sixties and the seventies, concurrent with the doubling of central office facilities, both single office buildings and large office parks also were constructed in large numbers in the suburbs. A 1976 survey, listing all structures with rental office space of 10,000 feet or more, showed that nearly 60 percent of this space was located outside the CBD (18). Suburban space can be cheaper than equivalent facilities in the CBD. It also offers cheaper, more convenient parking, convenience to the suburban homes of white collar workers, and open space with natural environmental amenities. Yet it has not precipitated a decline in the CBD. Rather, central and suburban space comprise two rather distinct markets serving predominantly different clients. Although some financial, legal, and energy firms have chosen decentralized locations, most remain anchored in the CBD. Suburban offices are chosen instead by firms requiring only occasional interaction with the central complex of legal and financial services. Among this group are administrative headquarters of industrial firms, who are principally concerned with internal operations and whose contacts with bankers and lawyers are sporadic; regional offices of national firms, whose financial and legal affairs are handled by offices in other parts of the country and whose business dealings are scattered among clients throughout the region; operations such as data processing, which have little need for access to services outside the firm; and local firms with suburban markets, whose needs for access are best served by offices close to their suburban customers. Only when ties to the legal-financial community are comparatively weak do suburban amenities exert substantial attractive force.

The vacancy statistics in Table 10-10 further substantiate the existance of two different markets for office space. These numbers do not

TABLE 10-10

Vacancies for a Sample of Office Buildings in the CBD and in the Rest of the Denver Region

Date	CBD Number of Buildings	CBD Vacant Space (Sq. Ft.)	CBD Vacancy Rate	Rest of Region Number of Buildings	Rest of Region Vacant Space (Sq. Ft.)	Rest of Region Vacancy Rate
May 1, 1973	—	298,003	7.0%	--	423,116	17.8%
Oct. 1, 1973	--	551,037	11.5%	--	184,358	10.7%
May 1, 1974	--	361,810	7.5%	--	173,335	7.9%
Oct. 1, 1974	—	629,606	13.0%	--	597,554	21.9%
Oct. 1, 1975	36	413,265	9.0%	110	1,132,218	25.0%
May 1, 1976	46	480,312	8.7%	109	1,876,039	32.8%
May 1, 1977	42	236,544	4.7%	89	1,007,135	26.5%

Source: (21)

cover all office space in the region but rather a representative sample of buildings, whose size and composition changes from year to year. Since 1974, the vacancy rate for suburban space has risen to several times the rate for CBD facilities. As new buildings have been added, downtown space has been quickly occupied, while many suburban offices have been left without tenants. These large and persistent disparities in market behavior indicate that the two kinds of space are not good substitutes for one another. If they were, such differences would be unlikely.

As in the retail sector, interviews with members of the downtown financial community confirmed the implications of the statistical data. All stressed the need for accessibility to other members of the CBD community as the dominant reason for choosing a site in the CBD. Other characteristics may be important to some office firms: the prestige of a downtown address; public relations benefits that accrue from a decision not to abandon the city; accessibility to clerical workers who must use public transit to travel to work. But, however important these attributes for the location decisions of particular firms, their contribution to the vitality of the office economy in the CBD is insignificant in comparison with the need for mutual interaction. Conversely, the amenities of the suburbs--the proximity to suburban homes, the convenient parking, the lower cost space, and green surroundings--are powerful only for firms where the need for interaction is weak.

SUMMARY OF FINDINGS

1) With respect to retail sales, all of the evidence examined - historical trends, forecasts, interviews, case studies, and aggregate and disaggregate modelling - suggest that the CBD faces strong competition from suburban alternatives. Both population and employment are shifting to the suburbs, and although there is some evidence that the absolute declines experienced by the City of Denver may halt, its share of the regional totals is likely to continue to shrink.

Any policies that place the CBD at a competitive disadvantage, including those which reduce the convenience or increase the cost of access by automobile, risk a substantial decline in downtown retail sales. The various retail analyses yield the following specific conclusions:

- All available evidence suggests that convenient parking makes an important contribution to the volume of sales and that lack of parking spaces with easy access to stores would cause a significant decline in business. Parking costs also appear to exert important impacts on the volume of business in downtown stores, though perhaps of less importance than parking location.

- If both cost and convenience affect the attractiveness of parking to shop downtown, parking that is cheap and less convenient may be an acceptable substitute for current spaces that are expensive and convenient. This conclusion is suggested by the disaggregate model results but is inconsistent with perceptions of merchants and scattered data from Denver. Experimental demonstrations seem a necessary prelude to serious consideration of such policies, because of their substantial risk of losses in sales.

- If the parking rate structure is changed to reduce costs for short-term parkers like shoppers while increasing long-term costs to discourage commuter parking, shopping trips to the downtown could increase, possibly significantly.

- Improved transit service would have a negligible impact on downtown retail business.

- The initial impact on sales of any change in transportation access may be multiplied several times over as shoppers adjust their shopping patterns in response to changes in the size of retail centers. A center that initially loses business because of transportation impacts will lose more business simply because it has become a smaller, less attractive place to shop. Initial growth will be similarly multiplied.

- The amenities provided in auto restricted zones, though not explicitly included in the two quantitative models of retail sales, appear likely to stimulate sales, especially if easy access for auto drivers is maintained. These zones are likely to be especially successful if they provide unique shopping opportunities in the CBD, reducing competitive pressure from the suburbs.

2) Although retail business in the CBD is very sensitive to the cost and convenience of access, the characteristics of downtown office activity are very different. This difference is readily apparent in the historical performance of the two sectors. The same inexpensive and convenient access provided to shoppers by suburban retail centers is provided to office workers by suburban office parks. Yet, while the downtown retail sector has fallen victim to suburban competition, the legal, financial, and energy activities of the region remain firmly anchored in the CBD. The need for mutual interaction has made the CBD much less vulnerable to suburban competition for these activities.

3) This historical performance suggests that downtown office activity would be much less sensitive than retail sales to transportation measures that restrict auto access to the CBD. The need for interaction will outweigh any incremental impediments to access caused by a rise in costs or a limit to capacity for centrally located long-term (work trip) parking.

4) Alternatives such as peripheral parking, with or without shuttle service, seem to be much more attractive substitutes for convenient parking for workers than for shoppers. For example, in a 1970 Denver survey, nearly 22% of CBD workers whose cars were parked during the peak midday period chose spaces outside the CBD; for shoppers, the fraction

was only 6%. Interviews with office managers and workers in downtown Denver suggest that many additional workers currently choose peripheral parking within the CBD, such as that offered by lots in the Skyline Urban Renewal Area. Demand by workers for parking spaces in the heart of the CBD is concentrated among those who need their cars several times during the day, such as sales representatives, and among upper income managers, whose salaries accommodate the higher cost of this convenience or whose companies provide the spaces for them. Any scheme to limit auto use in the heart of the CBD will have to consider the needs of those who use their cars in business and the opposition of others who currently choose to pay for convenience. But available evidence argues strongly that implementation of measures such as limits on convenient parking for workers will not significantly affect office location decisions.

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CHAPTER 11

EFFECTIVENESS OF AIR QUALITY TRANSPORTATION MEASURES

INTRODUCTION

Individual air quality transportation measures should be combined into a well-designed and coordinated program that balances disincentives with incentives, alleviates any inequitable aspects of particular actions, and allows for gradual implementation. Such an approach maximizes the probability of acceptance by both the public and government agencies, and thus increases the chances of successful implementation. This chapter presents the projected travel behavior and air quality changes resulting from three possible "program packages" for the Denver area. For both 1975 and 1985 conditions, the analysis focuses on the relative contributions of federal motor vehicle emission standards, vehicle inspection and maintenance, and possible VMT reduction measures. The three programs are designed to be increasingly severe, with the third containing fuel price increases as well as other control measures. In addition, because increased automobile taxes currently are proposed with some frequency, the effects of an increased automobile tax relative to fuel price increases and high occupancy vehicle incentives are analyzed because of the current frequency of these proposals. (Gasoline rationing and allocation schemes, however, are not included in any form.)

The emission reductions presented in other chapters and with the VMT figures in this chapter are in the form of percentage reductions from an estimated 1975 base condition. While this simple "roll-back" approach is useful for an initial identification of transportation/air quality

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[1] The transportation and air quality methodologies employed are those summarized in Chapter 1 and described in more detail in Appendices C and D.

effectiveness issues, it is deficient in that it does not explicitly take ambient air conditions into account and the emission reductions are being used as a proxy for actual air quality conditions. As such, certain information useful in analyzing CO hotspots and photochemical oxidant formation is missing.

To alleviate this potential weakness, and yet not duplicate the time and expense of the full air quality diffusion analysis already in use in Denver, an extension of the roll-back methodology was used in conjunction with a set of curves derived from the SAI model runs to estimate effects on ambient air quality levels. This "sketch planning" approach to air quality is described as part of Appendix D.

INTERRELATION OF WORK TRIPS, NON-WORK TRAVEL, AND AUTOMOBILE OWNERSHIP

The primary attention of most air quality transportation control plans has been on the trip between home and work and, consequently, the travel demand analyses presented in previous chapters also have focused on this particular trip purpose. However, in Denver commuting accounts for only 37 percent of total daily vehicle miles of travel, thereby leaving the remaining 63 percent of daily travel unaffected by the control plan. The mode of choice for work trips in a household, though, is not independent of non-work trip making and, further, studies have shown that automobile ownership decisions tend to be made simultaneously with the choice of the usual mode to work (1).

The behavioral travel demand models used in these analyses accordingly have been designed to explore the relationship between household auto ownership, work trip mode choice, and non-work travel. The hierarchy of travel choices reflected in these models is illustrated in Figure 11-1, which classifies travel-related decisions according to different time frames. The longest-term decisions made by an individual household (i.e., those that require most time to change or that are least frequently changed) relate to residential location, housing type, and workplace location. In the middle term, auto ownership decisions directly affect choice of transport for work trips. (In household travel planning, work trips are usually assigned higher priority than non-work travel and planned well in advance.) In this time frame, a household may change its auto ownership status and thus the usual transport mode of household workers. In the short term, various non-work travel decisions - seldom planned far in advance - depend

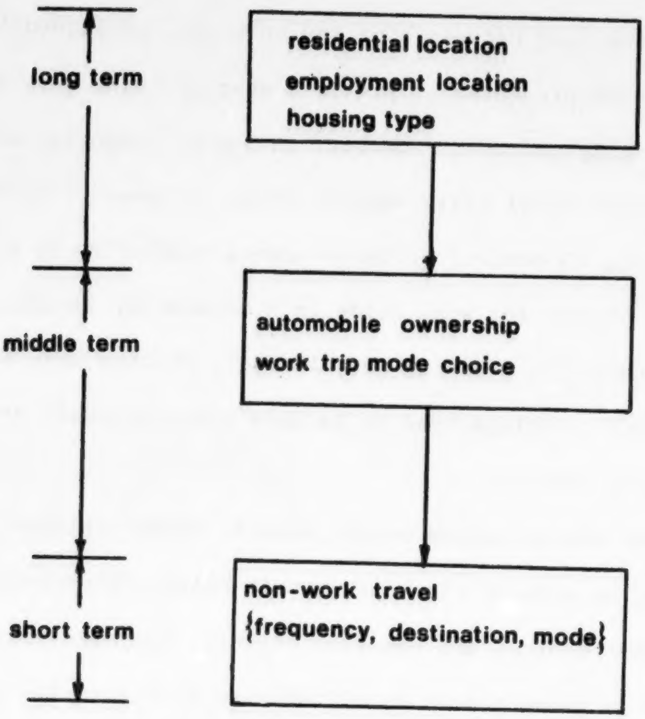
long term
middle term
short term
residential location
employment location
housing type
automobile ownership
work trip mode choice
non-work travel
{frequency, destination, mode}

FIGURE 11-1

The Travel Choice Heirarchy

on the availability of household autos after the work trip transport mode has been chosen. Such non-work travel is most logically thought of as a simultaneous choice of frequency (whether or not to make a specific trip), destination location, and travel mode. This formulation, for example, captures observed travel behavior during the 1973-74 fuel shortage, when many people either curtailed discretionary trips (i.e., reduced their frequency of travel) or switched destinations so as to have shorter travel distances (2, 3, 4). Since the primary concerns of this analysis are changes in travel behavior, emphasis has been placed on the middle- and short-term effects of particular measures.

The results of two policy analyses which explore the interrelationship of work travel, non-work travel, and automobile ownership are presented in Table 11-1.

A doubling of fuel price illustrates that non-work travel is more discretionary than the work trip, and that individual measures can have significant impacts on both the frequency and length of non-work trips. In contrast, for work trips, only shifts in transport mode are likely. Total daily VMT is reduced by 10.2 percent, composed of a 16 percent reduction in non-work travel and only a 0.7 percent reduction in work VMT. In turn, social-recreational trip making is more discretionary than shopping and other personal business travel, with vehicle trips decreasing by 3.1 percent vs 1.4 percent. The average non-work trip length, however, is decreased by 13.3 percent. These changes in non-work frequency and destination result in less than proportional changes between VMT, fuel, and emissions as a result of differing cold start effects, Figure 11-2. The 10.2 percent reduction in total daily VMT translates into a 10 percent fuel savings but only a 4.9 percent

TABLE 11-1

Interrelationship of Automobile Onwership, Work and Non-Work Travel

EFFECT		POLICY[1]	
		Double Fuel Price	Ride Sharing, Transit, Parking Package
Auto Ownership		-0.6%	--
Work	VMT	-0.7%	-4.0%
	Fuel	-0.7	-4.9
	HC	-0.6	-3.9
	CO	-0.6	-3.6
	NO_X	-0.8	-0.1
Non-Work	Shopping and Personal Business Vehicle Trips	-1.4%	+0.2%
	Social/Recreational Vehicle Trips	-3.1	+0.4
	Avg. Trip Length	-13.3	+0.4
	VMT	-16.0	+0.8
	Fuel	-16.2	-0.04
	HC	- 9.4	-0.05
	CO	- 8.5	+0.26
	NO_X	-17.7	+2.8
Total	VMT	-10.2%	-1.0%
	Fuel	-10.0	-2.3
	HC	- 4.9	-1.6
	CO	- 4.9	-1.5
	NO_X	-11.7	+1.1

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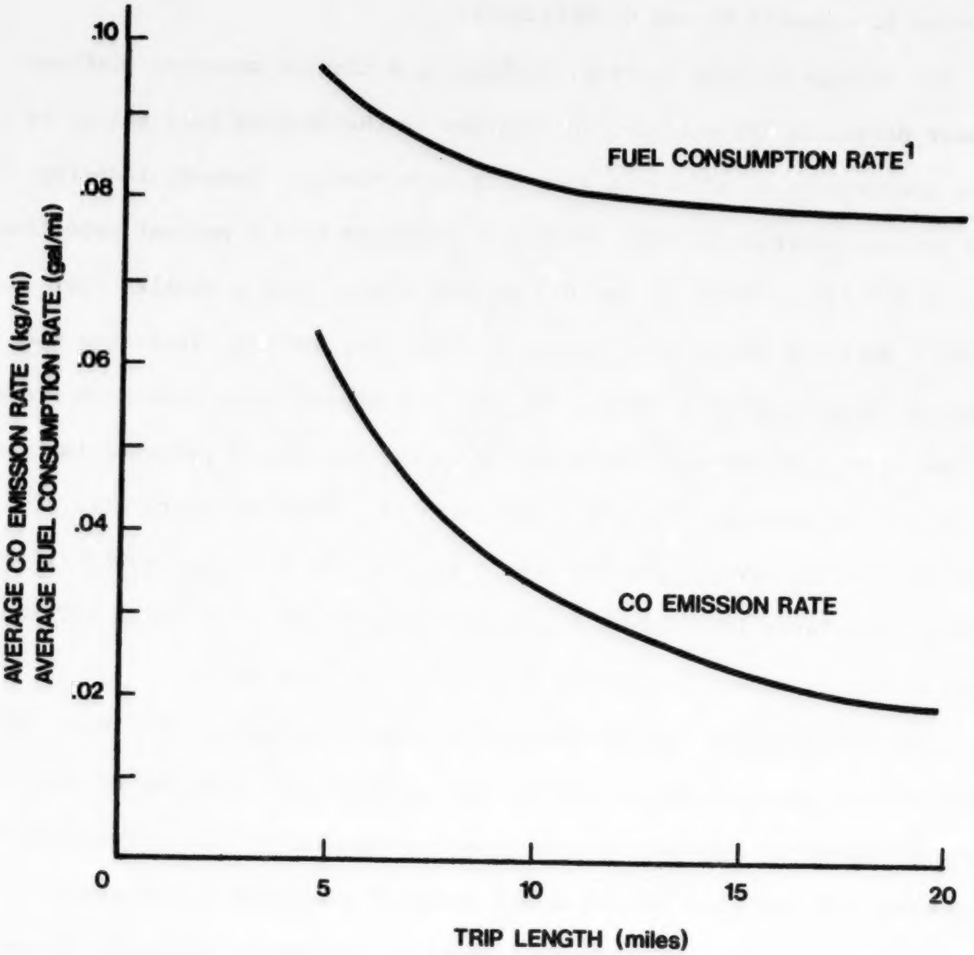
[1] Table entries are a percentage change relative to a 1975 base case.



[1] Based upon an average speed of 35 mph.

FIGURE 11-2

Average Fuel Consumption and CO Emission Cold Start Curves decrease in areawide HC and CO emissions.

The package of ride sharing, parking, and transit measures (defined in more detail in Table 11-2), in contrast to the doubled fuel price, is aimed exclusively at affecting work trip mode choice. Indeed, inducing a 12 percent increase in ride sharing contributes to a 4 percent reduction in work VMT (in contrast to the 0.7 percent change with a doubled fuel price). Shifting the work trip mode in this way, however, increases the number of autos available during the day to a household for non-work travel. In this case, non-work VMT increases by approximately 0.8 percent, implying a loss (or leakage) of just under one-third of a mile for every mile of work VMT that is saved. The net result is that the 4 percent work trip VMT savings translates into only a 1 percent reduction in total daily VMT compared to the 10.2 percent savings with a doubled fuel price.

Some TCP measures can be expected to result in middle- and long-term reductions in auto ownership levels. For example, the doubling of fuel price in Denver is forecast to reduce auto ownership by 0.6 percent, while an annual $250 registration fee would decrease ownership by 1.9 percent. These figures assume only a change in overall automobile ownership levels, without any corresponding shift in auto type. The automobile registration fee, though, could vary as a function of vehicle fuel efficiency. Further, a doubling of fuel price could be expected to produce changes in auto ownership to more fuel efficient cars (with no corresponding decrease in vehicular emissions, since emission rates do not vary by vehicle). In a Washington, D.C., travel analysis, a doubled fuel price resulted in a 4.7 percent reduction in fuel consumption if no changes in auto ownership were taken into account but a longer term 15.1 percent savings if both changes in auto ownership level and type were considered (5).

PROGRAM PACKAGES

The travel analysis findings described so far have been largely in terms of individual program measures so that the specific effects could be more easily isolated and understood. A program that combines individual measures into a well-designed and coordinated package, however, may be both more effective and equitable. Three such "program packages" are examined in this section, relative to 1975 base conditions. In the next section, selected program measures then are re-analyzed in terms of projected 1985 socioeconomic conditions so that the effects of both the federal motor vehicle emissions standards and vehicle inspection and maintenance regulations can be determined.

The three program packages analyzed are summarized in Table 11-2 and consist of combinations of ride sharing, transit, parking, preferential treatment and pricing measures. The packages have been designed to become increasingly severe in their control. Effects on work trip modal shares are tabulated in Table 11-3; areawide impacts on VMT, emissions, and fuel are displayed in Table 11-4 and also Figure 11-3.

The first package is the most moderate of the three, resulting in a 1.8 percent decrease in areawide work VMT. While this package contains both CBD parking charges and improved CBD transit in addition to an areawide carpool program, the two CBD measures add only .3 percent to the areawide VMT reduction compared to the carpool program taken by itself.

The second package adds a vanpool program, further transit improvements, parking restrictions, and areawide auto level of service improvements. The result is a 4 percent reduction in work VMT and a 1 percent decrease in daily VMT; only minor changes occur in non-work travel. When compared to

TABLE 11-2

Alternative Program Packages

Measure	Program		
	1	2	3
Ride Sharing	Employer Promotion and Matching in all firms with 50 or more employees	Employer Promotion and Matching in all firms with 50 or more employees; Vanpooling available in all firms with 250 or more employees; Transit fare subsidy of 50% available to all workers; Preferential carpool parking	Same as No. 2
Transit	Improved frequency on CBD routes	Improved frequency on CBD routes; 20% reduction in in-vehicle travel time for CBD routes	25% areawide improvement in frequency; 20% reduction in in-vehicle travel time for CBD routes
Parking	Increased commuter parking costs in CBD by $1.00 per day	Increase commuter costs in CBD by $1.00 per day; Reduce parking availability so that round trip walk times are increased by 10 minutes	Increase commuter costs areawide by $1.00 per day; Reduce areawide parking availability so that round trip walk times are increased by 10 minutes
Preferential Treatment	--	Improve areawide level of service for all vehicles by 5%	Same as No. 2
Pricing	--	--	Triple the price of fuel in terms of 1965 dollars

TABLE 11-3

Predicted Areawide Work Trip Modal Share Impacts of Program Packages

Program Package.	Auto Ownership Vehs./Household	Percent Change			
		Work Trip Modal Shares (Percent)			
		Drive Alone	Shared Ride	Transit	Vanpool
Base (Avg./Day)	1.43	0.78	0.19	0.03	0.0
1	--	-3.3	13.3	-0.1	--
2	--	-4.6	11.7	-6.3	(0.01)*
3	-1.4	-6.2	15.7	48.2	--

*New Modal Share

TABLE 11-4

Predicted Areawide Impacts of Program Packages

Program Package	PERCENT CHANGE						
	VMT (miles/day)			Fuel Consumption (gal/day)	Auto Emissions (kg/day)		
	Work	Non-Work	Total		HC	CO	NO_x
Base (Avg./day)	12.8	19.85	31.55				
1	-1.8	0.3	-0.5	-1.1	-0.8	-0.7	+0.6
2	-4.0	0.8	-1.0	-2.3	-1.6	-1.5	+1.1
3	-4.3	-22.0	-15.3	-18.0	-9.0	-9.0	-15.4

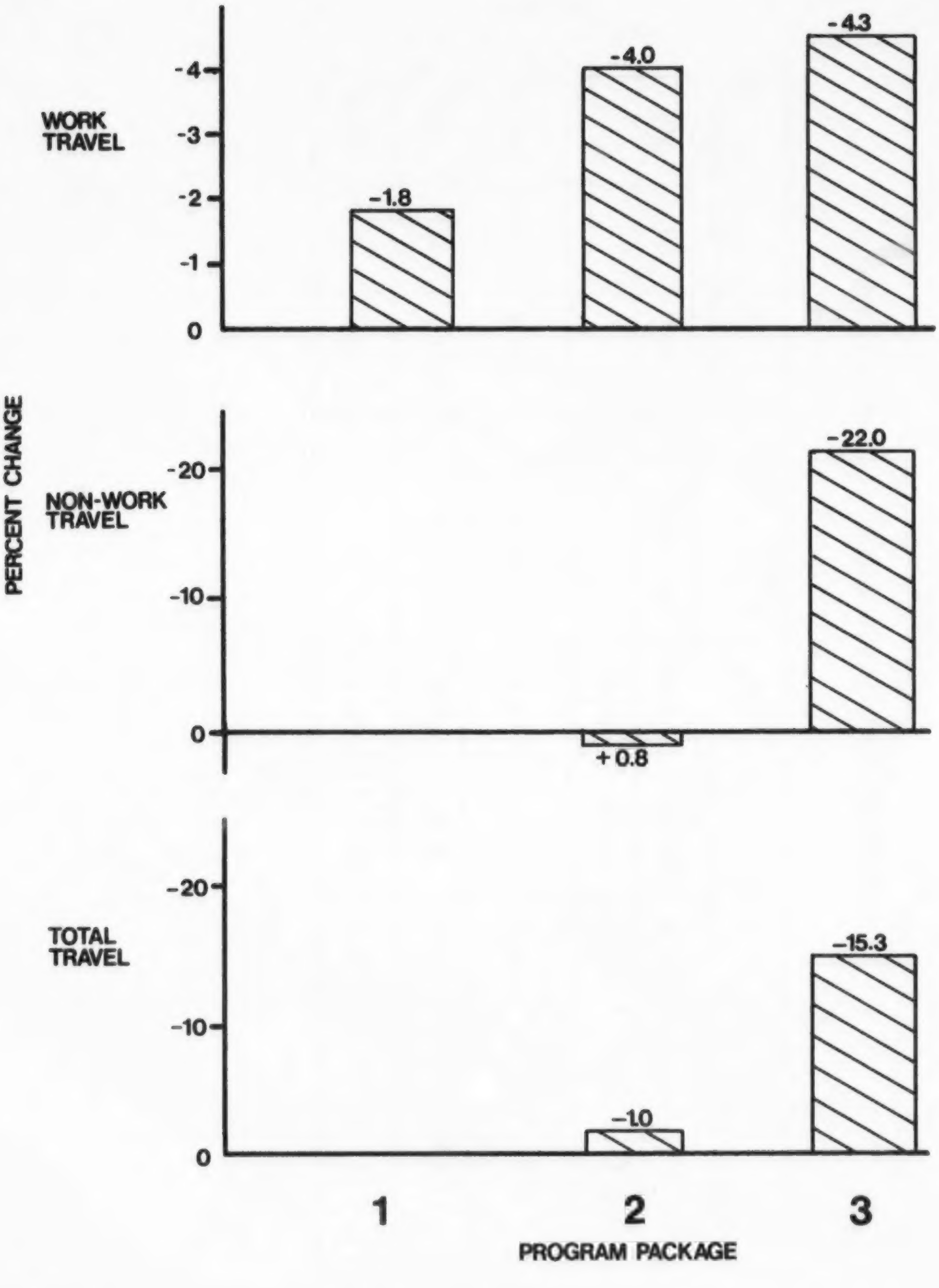


FIGURE 11-3

Percent Change in Daily Vehicle Miles of Travel the individual program measures, the improved transit and auto level of service result in less of a shift to vanpooling and consequently less of a reduction in VMT; emissions and fuel consumption changes, however, are higher.

The third program package introduces a tripling of the cost of fuel (in terms of 1965 dollars) along with an areawide parking management program and additional transit improvements. The result is a 15.3 percent reduction in daily VMT, an 18 percent decrease in fuel consumption, and 9 percent reductions in HC and CO emissions. Work trip VMT savings, though, are essentially the same as those with the second package, 4.3 percent compared to 4 percent. The difference occurs in non-work travel with reductions of 1.6 percent in shopping person trips, 4.8 percent in social/recreation person trips, 21.1 percent in average trip length, 22 percent in non-work VMT, and 26 percent in non-work fuel consumption. Auto ownership levels in this case are forecast to be 1.4 percent lower than in the base case. The largest contributing factor to these changes clearly is the effect of the increased fuel price on non-work travel.

PROJECTED 1985 CONDITIONS

Most program measures, as demonstrated in previous chapters, normally take several years to achieve full implementation. For example, the Colorado Legislature passed, in 1977, vehicle inspection/maintenance provisions to become effective in 1980. Federal motor vehicle emission standards are in effect that will further reduce new car emissions of all vehicle pollutants. While the majority of the travel analyses have been presented in terms of 1975 conditions so as to better isolate the effects of individual program measures, it is more realistic to examine a point in time 5-10 years in the future to assess the full effects of all emissions related controls. For purposes of this analysis, 1985 was selected as an appropriate year.

To reflect 1985 socioeconomic and travel conditions as accurately as possible, the following changes were introduced to the 1975 data base:

- population levels and distribution were changed according to DRCOG projections (6);
- employment levels and distribution were changed according to DRCOG projections (7,8), including the destination of work trips and both the levels and distribution of retail and service employment affecting non-work travel;
- income level, in real dollars, would increase an average of 3 percent per year, based on projections of the U.S. Department of Commerce, Bureau of the Census (9);
- motor vehicle emissions changes according to EPA projections (10)[1];
- transit fare and gasoline price would increase with inflation but would not change in terms of real dollars;
- transit service area and frequency would remain the same as in 1975;

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[1] These analyses were performed prior to passage in August, 1977, of amendments to the Clean Air Act. Accordingly, the results do not reflect the delayed schedule in either motor vehicle emissions or high altitude standards created by these amendments. Consequently, reductions in vehicle pollutants will be less than those forecast.

- off-peak level of service for auto and transit would remain the same as in 1975; and
- peak period level of service for auto and transit would remain the same as in 1975 except at existing points of congestion where additional delays would occur as a result of the overall growth in employment.

The results of the 1985 travel demand analyses are illustrated in Figure 11-4, displaying percent changes in 1985 areawide totals relative to 1975, and Figure 11-5, showing percent changes in 1985 average household values relative to 1975. A growth of 27 percent in areawide population and of 38 percent in total employment results in increases of 35.4 percent in work VMT and 65.4 percent in transit ridership. While total travel increases, the effect of the federal motor vehicle emissions standards is overall decreases of 41.7 percent, 61.9 percent and 55.4 percent in HC, CO, NO_x emissions respectively. The projected effect of a vehicle inspection and maintenance program is a further reduction of 3.9 percent in HC emissions, 8.1 percent in CO emissions, and 1.3 percent in NO_x emissions.[1] The results are total areawide decreases of 45.6 percent, 70.0 percent and 56.7 percent in HC, CO and NO_x emissions.

These same general patterns follow when average household values are examined. Average household auto ownership levels are 8.0 percent higher than in 1975, largely because of the larger number of workers per household and the growth in real income. Again, because of the federal motor vehicle standards, average household emissions are forecast to decline by 56.7 percent for HC, 75.7 percent for CO, and 61.5 percent for NO_x (including the benefits of vehicle inspection and maintenance).

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[1] The emission reductions associated with vehicle inspection and maintenance are based on data contained in EPA Appendix N, 1977 (11). The estimates of I/M effectiveness contained in Chapter 4 are based on Colorado APCD analyses and are somewhat more optimistic.

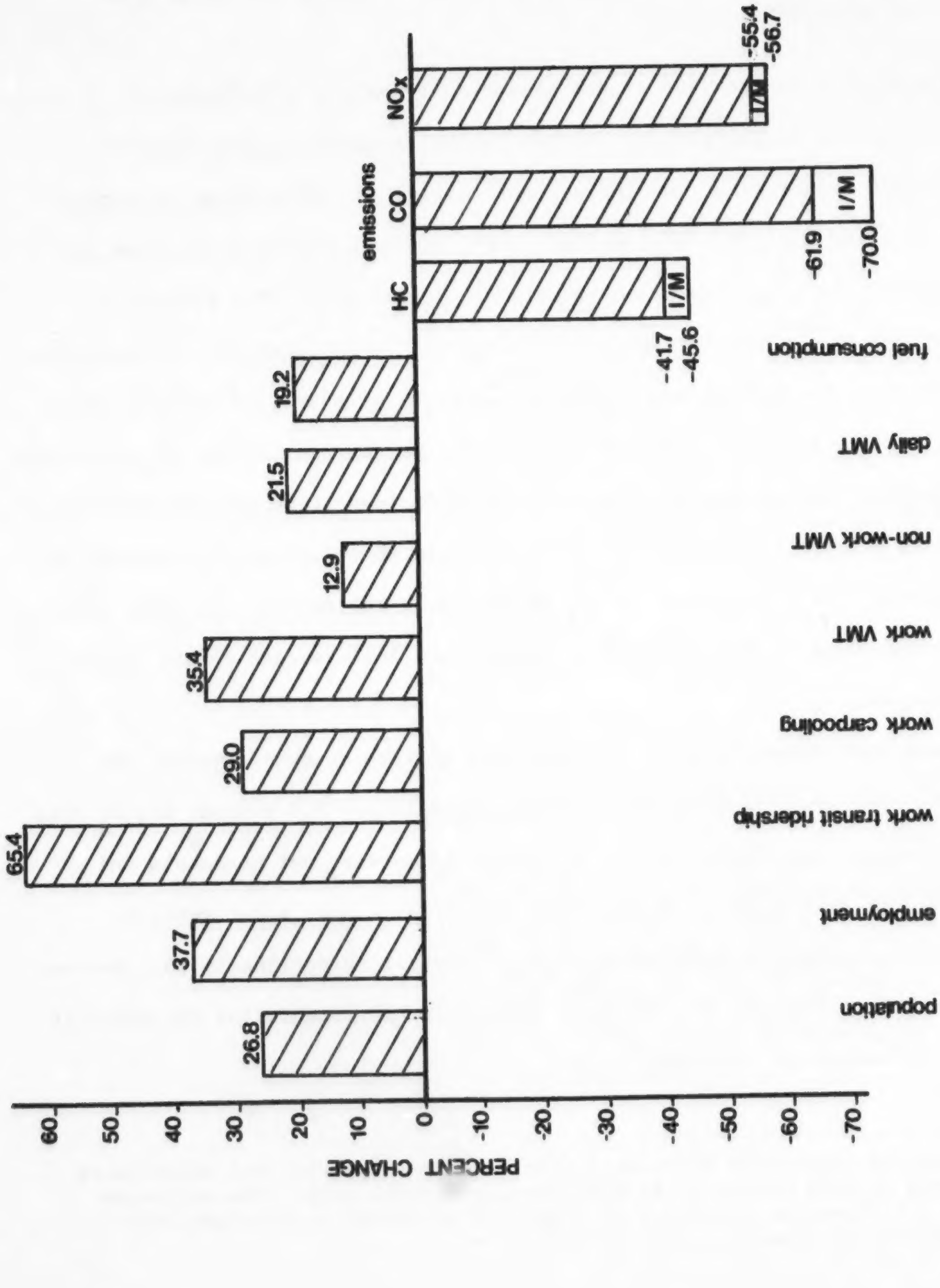

FIGURE 11-4

1985 Projected Changes in Total Travel and Emissions

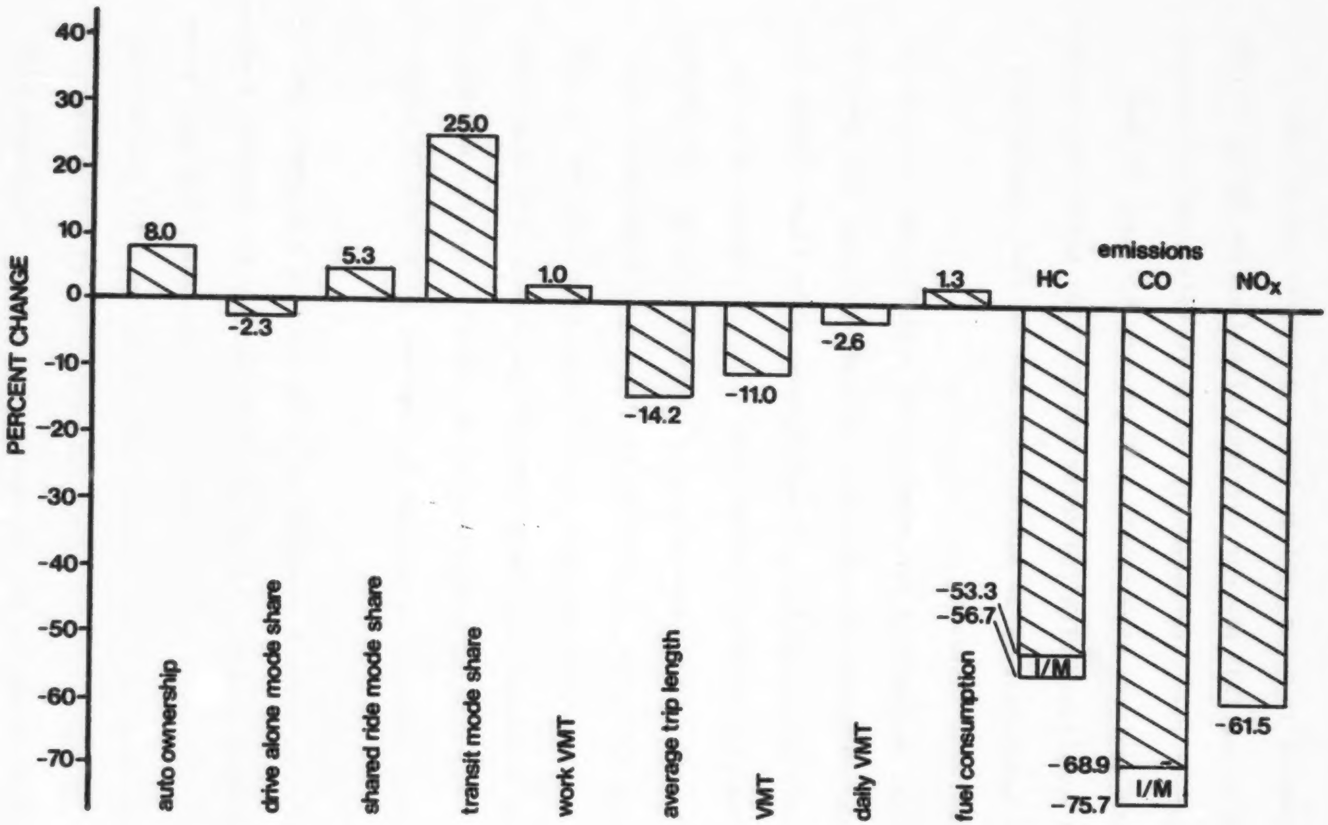

FIGURE 11-5

Changes in Average Household Travel and Emissions, 1985-1975

The data presented in Figures 11-4 and 11-5 do not account for the anticipated improvements in motor vehicle fuel economy resulting from compliance with the 27.5 mpg 1985 new car average defined by the Energy Policy and Conservation Act of 1975. Consequently, while CO emissions are reduced by 62.0 percent, the analyses show nearly a 20 percent increase in fuel consumption. Full compliance with the motor vehicle fuel standards, however, would result in an approximately 30 percent decrease in fuel consumption rather than the indicated increase.

To determine the incremental contribution of possible VMT controls to 1985 air quality improvements, two candidate program measures were analyzed, with and without vehicle inspection and maintenance. The first, Table 11-5, is an employer-based ride sharing package consisting of carpool matching and promotion with both preferential and free carpool parking. The incentive is available in all organizations having 50 or more employees. This package produced a 1.7 percent decrease in 1975 work trip VMT, and is projected to result in 4 percent less work trip VMT growth in 1985 than otherwise would occur. Incremental reductions in HC and CO emissions are approximately 1 percent each compared to 4.8 and 8.2 percent with vehicle inspection and maintenance.

The second program measure examined is a CBD parking management policy consisting of increased parking charges of $1.00 per day for workers combined with relocated parking supply so that walk time is increased for auto modes by an average of 10 minutes. The result, Table 11-6, is a 3.7 percent decline in VMT for CBD-destined work trips and reductions of 1.5 percent, 1.0 percent, and 1.3 percent in HC, CO, and NO_x emissions. Combined with vehicle inspection and maintenance, this parking management program

TABLE 11-5

Marginal Effectiveness of Alternative Program Measures, 1985

Work Trip Impacts [1]

Policy	Work Trip Mode Split				Work Trip VMT (Miles/Day)	Work Trip Fuel Consumption (Gal/day)	Work Trip Auto Emission (KG/day)		
	Drive Alone	Shared Ride	Transit	Vanpool			HC	CO	NOX
Vehicle I/M	0	0	0	-	0	0	-4.8	-8.2	-1.8
Ride Sharing Package	-4.8	+12.9	-20.0	-	-4.0	-3.0	-1.2	-0.8	-1.4
Combination	-4.8	+12.9	-20.0	-	-4.0	-3.0	-5.9	-9.4	-3.1

[1] All values expressed as differences between 1985 projected and base conditions, relative to 1975.

Table 11-6

Marginal Effectiveness of Alternative Program Measures, 1985

CBD Work Trip Impacts[1]

Policy	Work Trip Mode Split				Work Trip VMT (Miles/Day)	Work Trip Fuel Consumption (Gal/day)	Work Trip Auto Emission (kg /day)		
	Drive Alone	Shared Ride	Transit	Vanpool			HC	CO	NOX
Vehicle I/M	0	0	0	0	0	0	-4.8	-8.2	-1.8
CBD Parking Management	-4.3	-0.6	+20.4	-	-3.7	-3.7	-1.5	-1.0	-1.3
Combination	-4.3	-0.6	+20.4	-	-3.7	-3.7	-6.2	-9.1	-3.1

---

[1] All values expressed as differences between 1985 projected and base conditions, relative to 1975.

would result in further emissions reductions of 6.2 percent, 9.1 percent and 3.1 percent over what would be obtained with only the federal motor vehicle emission standards.

AIR QUALITY IMPLICATIONS

While a preliminary assessment of the air quality implications of both individual measures and combinations of measures can be based on the tabulated percentage reductions of emissions, an improved estimate can be obtained by relating emission reductions to changes in ambient air quality. As an example, the third of the three candidate program measures is considered.[1]

The two pollutants of primary importance are carbon monoxide and photochemical oxidants. Table 11-4 shows a 9.0 percent decrease in CO emissions resulting from program 3. Since autos account for about 73 percent of all CO, the corresponding reduction in 1975 total CO emissions is 6.6 percent. But the total reduction required to attain the standard for CO is 48 percent. Thus, even a stringent program incorporating many disincentives to auto use cannot begin in the short term to approach the standard.

The effect on oxidant concentrations is computed by first determining the effect on HC and NO_x levels and then employing the graph shown in Appendix D to determine the effect on O_3. HC emissions drop 9 percent in response to program 3, but since autos contribute only 55 percent of the total hydrocarbon burden, the net effect on total HC emissions is only about -5 percent. Thus, from an initial level of .38 parts-per-million (ppm), HC levels would drop to .36 ppm. NO_x emissions decline by 15.4 percent; with autos contributing 32 percent of the total NO_x burden, the net effect is -4.9 percent. Thus, from .06 ppm, NO_x levels would drop to .057 ppm.

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[1] The methodology employed in relating percent changes in emissions to corresponding changes in ambient air quality is described as part of Appendix D.

From the graph in Appendix D, the ozone concentration corresponding to the new HC and NO_x levels is .134, or about 5 percent below the initial level of .141. This is quite small in comparison with the 43 percent reduction required to meet the oxidant standard. Nevertheless, it could represent a useful step in the direction of attainment - if it had a reasonable chance of implementation.

As a second example, the improvement in 1985 air quality resulting from the Federal Motor Vehicle Control Program (without inspection and maintenance) can be examined. Using the same approach employed above for the program 3 data, and the emissions reductions for 1985 shown in Figure 11-4, the following improvements in air quality over 1975 base conditions are obtained[1]:

Pollutant	Required Reduction	Actual Reduction
CO	48%	45.2%
Oxidant	43%	16.3%

According to these results, Denver would have been very close to achieving the CO Standard in 1985 without the implementation of any other transportation controls. The same is not true for oxidants; considerable further improvement would be necessary. With an inspection and maintenance program in force, the CO reduction would be 51 percent and the oxidant reduction would be 18.4 percent. Thus, an inspection and maintenance program could result in attainment of the CO standard, but would make only a moderate contribution to improved oxidant levels.

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[1] Again, it should be noted these results do not account for the revised emission standards resulting from the 1977 Clean Air Act Amendment.

SUMMARY OF FINDINGS

1) The implementation of air quality transportation controls can result in a complex set of transportation behavior changes involving auto ownership, non-work as well as work travel, and decisions regarding trip frequency and destination choice as well as travel mode. A system of disaggregate travel demand models, equivalent to that demonstrated here, that is capable of analyzing travel behavior at the individual household level is essential to a full understanding of these potential impacts. Attributes relating not only to transportation level-of-service but also to household socioeconomic conditions and to alternative destination locations should be taken into account.

2) The travel behavior analyses performed, confirmed by actual observation, indicate that work travel is far less discretionary than either shopping or social/recreational non-work travel. Given their choice, individuals will change the destination and freqency of non-work trips before changing their usual mode of travel to work. For example, a doubling of fuel price is projected to result in decreases of 0.7 percent in work VMT, 16 percent in non-work VMT, 1.4 percent in shopping trip frequency, 3.1 percent in social/recreational trip frequency, and 13.1 percent in average non-work trip length.

3) With the exception of vehicle inspection and maintenance, Denver's transportation controls are directed primarily at the trip between home and work, a trip purpose which constitutes 37 percent of daily travel. Further, with the exception of the ride sharing program, the remaining four controls are aimed principally at work trips to the central business district, constituting approximately 10 percent of areawide work travel.

Denver's VMT controls, with the possible exception of a parking management plan, can be characterized as incentives, as opposed to disincentives, available on a voluntary basis. Such incentives, in the absence of more direct measures limiting or at least discouraging driving alone, will result in only minor changes in areawide travel behavior, VMT reduction, and ambient air quality. On an individual basis, though, the measures are typically highly cost-effective.

4) Air quality transportation controls should be designed as a coordinated package consisting of several individual program measures. These measures can include disincentives as well as incentives, and can be combined so as to both avoid issues of equity and provide visible alternatives to the drive-alone automobile. Such measures also should be designed to achieve full compatibility with federal motor vehicle emission and fuel standards and with possible state vehicle controls as well. An example of a possible program containing ride sharing, transit, preferential treatment, traffic operations, and parking management is forecast to reduce 1975 work trip VMT by 4 percent, areawide fuel consumption by 2.3 percent, and HC and CO emissions by 1.6 percent and 1.5 percent respectively. The addition of a tripled fuel price along with other measures increases the total daily VMT savings from 1 percent to 15.3 percent.

5) An examination of projected 1985 socioeconomic and travel conditions in Denver indicates that the federal motor vehicle emission standards will be responsible for the largest reduction in vehicle emissions, followed by vehicle inspection and maintenance. While total population will grow by 27 percent and daily work trip vehicle miles of travel will increase by more

than 35 percent, it is forecast that reductions of 46 percent, 70 percent, and 57 percent will occur in HC, CO, and NO_x emissions. An examination of candidate work trip VMT measures indicates that the contribution of vehicle inspection and maintenance to emissions reductions in 1985 will be approximately four times greater for HC and eight times higher for CO than those of the VMT measures taken individually.

6) Improvements in 1985 ambient air quality of 51 percent in CO and 18.4 percent in photochemical oxidant levels are projected to result from compliance with the federal motor vehicle emissions standards and implementation of a vehicle inspection and maintenance provision. These compare to required improvements of 48 percent and 43 percent respectively. Thus, while no additional controls are required to achieve the CO standards, projected oxidant levels will still be far in excess of the standard.

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CHAPTER 12

IMPLICATIONS FOR AIR QUALITY/TRANSPORTATION PLANNING

TRANSFERABILITY OF PROGRAM MEASURE FINDINGS

Experience with the six major program measures of Denver's air quality/transportation plan have been examined in previous chapters, with emphasis on the operational, institutional and administrative characteristics unique to each measure. Reasonably detailed informaton on the benefits, costs, problems, and opportunities of the measures are provided. The observations, though, are based primarily on the experiences of a single urban area--Denver, Colorado. While the Denver region clearly has numerous unique characteristics--its altitude and the nature of its air quality problem, its high population growth rate, the particular balance of local and state authority, and its high level of environmental awareness--the study results and methodologies generally appear to be applicable to most other urban areas that need to develop and implement transportation/air quality plans. Furthermore, examination of other cities both in this study and in other research efforts show marked parallels in experience and consistency in observed effects.

The basic travel behavior, energy, and air quality analysis methodologies utilized in Denver should be directly transferable to other areas. They already have been applied successfully in Washington, DC; Birmingham, Alabama; Ft. Worth, Texas; and San Francisco, California. Neither data availability nor the resources available to an urban area should prove to be a constraint on the use of these methods. Household, travel, and socio-economic data necessary are readily obtainable from a variety of sources (or are already in use), and the required personnel skills currently exist in most urban transportation planning organizations.

The findings of the program measure and impact analyses, though more dependent on the characteristics of Denver, also are basically transferable to other urban areas. Examination of experience in other cities demonstrates a remarkable degree of consistency, as has been demonstrated in the discussions on individual program measures. In numerous urban areas, implementation of transportation/air quality plans has been slower than desired; and results, though significant at the project level, have been less than anticipated on an areawide basis. Most metropolitan regions claim to have their own particularly complex political and institutional structure--but in many ways, the issues are not unlike those in Denver. Similarly, the same concerns over potential transportation, cost, air quality, energy, social and economic impacts have been raised in most metropolitan areas. While Denver's private interest groups may be better organized and more effective than in some--but not all--cities, the same basic set of automotive, economic, environmental, and neighborhood interests are present in all urban areas and raise very similar issues. Consequently, we believe that the Denver setting, though certainly not devoid of uniqueness, has assisted in developing a better understanding of the prerequisites for effective implementation and administration of transportation/air quality measures. Whether the objective is air quality, energy conservation, transportation system management--or all three--Denver's lessons, barriers and opportunities, also are applicable to other American cities.

OVERALL FINDINGS

A comparison of individual program measure observations indicates a remarkable degree of consistency.

1) The tight deadlines of the 1970 Clean Air Act and the severity of the Denver air quality problem combined to make it impossible to meet the ambient air standards on time. However, both the TCP requirement and, more recently, the 109(j) consistency requirement have contributed significantly to the initiation of studies and the implementation of measures which will improve air quality. These requirements have necessitated that state and local transportation agencies give air quality explicit and thorough consideration and have prodded the agencies to take reasonable steps to improve air quality. The provisions of the 1977 Clean Air Act Amendments provide significant opportunities to build upon and strengthen the progress and successes to date and to accelerate the implementation of measures to improve air quality. Nevertheless, a concerted effort will be necessary to meet the new deadlines.

2) The planning and implementation processes for air quality improvements (State Implementation Plans), for energy conservation (State Energy Conservation Plans), and for more efficient transportation systems management (TSMEs) are, in general, compatible. Greater integration of the three programs, however, is desirable to reduce paperwork and red tape and to maximize the benefits of the dollars being spent on short range transportation measures. However, the responsible federal agencies--EPA, DOE, and DOT--currently put differing degrees of emphasis on the three objectives. Collapsing the programs into one

will not be effective unless DOT develops mechanisms to insure air quality and energy conservation, as well as other social and environmental considerations, are given greater emphasis in transportation decision-making.

3) VMT reduction measures, if properly designed and coordinated, can contribute to a number of objectives--not only air quality improvement and energy conservation, but also savings in commuting expenses, improved urban aesthetics and ambience, and more efficient use of transportation facilities. By the same token, the CBD-oriented measures can have adverse economic effects if they are not designed to achieve some of these secondary benefits. Reductions in auto accessibility should be carefully balanced by incentives which otherwise compensate for potentially adverse effects. In this regard, measures which are aimed at work trips but leave shopping trips unaffected (or even improve accessibility for shoppers) are particularly attractive.

4) One of the difficulties in implementing transportation management programs, whether for air quality improvement or for energy conservation, is that a sizeable portion of the population, as well as many agency officials and elected representatives, still are not convinced that problems exist or that the problems are serious enough to justify special action. However, there is evidence that both planning and implementation of control measures can increase the general awareness and appreciation of air quality and energy issues, and that this consciousness-raising in turn stimulates voluntary actions that contribute to air quality and energy goals.

5) The requirements for institutional cooperation often are greater for transportation/air quality measures than for many large capital projects; jurisdictions often overlap, and "support" actions often are needed. The costs of administration and coordination also can be a higher percentage of total cost for such a project than for a more traditional highway or transit project. Both of these factors tend to make agencies reluctant to take on responsibility for measures that are intended primarily to improve air quality. They also make it easier for agencies to pass the buck with regard to implementation responsibility.

6) Each of the VMT reduction measures examined is individually cost effective, and although areawide impacts are modest, each does have a positive air quality impact. However, each of the measures has numerous design details and problems to be worked out and, as experience in Denver and elsewhere has shown, active (inspired) leadership and continuing followup by a small number of individuals is needed to get a measure going and to keep it going.

7) There are few significant cost or administrative barriers to impede implementation of VMT reduction measures. With the exception of capital intensive new construction, they are relatively inexpensive, and most are within the current authority of one or more agencies. Barriers do exist, though, in terms of political and institutional unwillingness to generate controversy or to go against vested interests, and in the sense that implementation of the measures may not match the cognizant agency's priorities.

8) The effectiveness of an individual measure in meeting air quality (or energy) objectives is dependent on the size of the market it reaches. The federal emissions program, which reaches all new

automobiles, is a most effective way of reducing pollution. Vehicle inspection/maintenance similarly has a sizeable effect since it reaches all autos in use and thus all trips, both work trips and those made for other purposes. However, the majority of the VMT reduction measures contained in transportation/air quality plans (including Denver's) are directed towards work trips, and many are aimed primarily at CBD-ending work trips. As such, they affect a relatively small percentage of the trips being made, and although they still are cost-effective, their regional impact necessarily will be small.

9) The lack of consensus on growth and development policy for the Denver region has complicated all planning and implementation efforts, including population and land use forecasting, highway and transit systems development, and water resources planning, as well as air quality attainment and maintenance programs. Competing recommendations on each of the programs and the state of flux inherent in a rapidly growing region have made the always-difficult job of predicting future conditions especially fraught with uncertainty. This uncertainty further complicates the problem of getting support for a particular course of action. Nevertheless, agencies in the Denver area have demonstrated that it is possible to implement individual measures, if not overall programs. Examination of other urban areas shows that Denver is not alone on any of these matters.

10) The study demonstrates that "sketch planning" or simplified analysis techniques can provide useful information on the effectiveness and the impacts of transportation/air quality measures. Application of such techniques is relatively inexpensive and their use feasible

in light of the resources normally available to state and regional agencies. In fact, in most cases, their use would result in savings in both time and money compared to the utilization of more comprehensive model systems.

IMPLICATIONS FOR FEDERAL TRANSPORTATION/AIR QUALITY POLICY

The 1977 Amendments to the Clean Air Act offer opportunities for avoiding many of the problems which arose in early TCP planning and implementation. The amendments emphasize the establishment of a process for transportation/air quality planning which is characterized by lead responsibility at the regional level; shared and agreed-upon state, regional, and local authorities and obligations; requirements for consideration of alternative measures and programs and for evaluation of social and economic impacts; a standard of "reasonable incremental progress" in implementing measures to improve air quality; and shared federal responsibility for ensuring that transportation/air quality measures are in fact introduced. In addition, this process is to be integrated with other metropolitan planning efforts, and the assessment of the results will no longer be made on the basis of a separate transportation/air quality plan, but instead on the overall achievements in air quality improvement taking all relevant activities into consideration. The emerging process, then, would have "self-enforcing" provisions for the compatibility of air quality planning and transportation planning: the separate state implementation activities. And the process would include a system of procedures, incentives, and sanctions designed to ensure that reasonable progress in implementing air quality improvements actually would occur.

Although the emerging transportation/air quality process offers greatly increased potential for success, several questions remain. The major objective of the proposed process is to shift transportation planning away from merely considering air quality toward actual implementation of air quality improvement measures. If this objective is to be attained, two major issues must be resolved favorably:

1. MPO Capabilities and Relations with Other Agencies.

Currently, most MPO staffs carry out feasibility studies and conduct certain areawide planning efforts, but primarily they summarize and compile the planning and programming activities of local and state agencies and operators. State and local agencies often have the primary responsibility for implementation. In order to achieve the goal of regional and subarea air quality improvement, it will be necessary to mobilize these disparate agencies and organizations for coordinated action. As planning agencies, MPOs simply do not have the authority, nor do they have the mandate, to direct other agencies to conduct studies or implement measures. Therefore, if coordinated action on air quality is going to occur, it will be largely dependent on the MPO, in its role as a consortium of local (and state) officials, orchestrating an agreement that the members individually will assume the appropriate responsibilities for air quality improvements. MPO actions including "lend a planner" programs, pass-through funding earmarked for particular studies or projects, and MPO-conducted studies of promising actions would be valuable. Nevertheless, the proposed process will necessitate goal-oriented commitment and responsibility on the part of local agencies and officials to a greater degree than has typically occurred in the past, plus stronger direction from the MPO as a forum and as a planning staff, than has been common.

Support from the federal agencies - particularly the Department of Transportation - will be needed if the MPOs are to succeed. This support appropriately might include additional funding for planning and implementation of air quality measures; assistance which would enhance skills necessary to conduct the needed analyses - through training programs and workshops, for instance; and the effective packaging and dissemination of reports, analysis tools, and similar information which would be of assistance to the MPOs and their state and local counterparts.

2. Agreement to Implement Programmed Commitments

The transportation control planning experience of the past five years demonstrated the difficulties of implementing measures which are perceived by the public as imposing direct and immediate costs or inconveniences in return for modest reductions of dangers which are uncertain, indirect, diffuse, and long-term. Although the proposed transportation/air quality planning process includes provisions for informing the public about air pollution problems, on one hand, and for selecting the most cost-effective, least disruptive measures possible, on the other, there is little reason to believe that political resistance to at least some of the proposed measures - auto disincentives, for example - will fade away. In some areas, attainment by 1987 may be possible through some combination of reduced emissions from a better controlled and maintained vehicle fleet, with only a modicum of voluntary programs and transit improvements for good measure. In the metropolitan areas having the worst air pollution problems, however, attainment may necessitate the implementation of measures which do impose certain restrictions on auto mobility, increase costs, or both. No doubt, these measures will be controversial, and judicious use of incentives, sanctions and lobbying will be necessary to achieve implementation.

The 1977 Amendments' public information programs on air quality issues would be enhanced by a clear federal stance - from DOT as well as EPA - in support of air quality improvements. Implementation of transportation measures which improve air quality is likely to be heavily dependent on continuing "pushes" for demonstrated progress. In the past, many metropolitan areas have relied on "consideration" of air quality as a sufficient demonstration of compliance with the Clean Air Act, even when planning and programming activities showed little progress in implementation of measures with the potential to improve air quality. In fact, in many areas even relatively non-controversial incentives have been delayed. Certainly the assessment of how much progress is "reasonable" is always dependent on facts and circumstances, and each case will depend on intensive and complex negotiations and on compromises. Nevertheless, it would be invaluable to have a clear joint EPA/DOT policy that the transportation/air quality planning process will be adequate only if it produces planning commitments,and programming,and implementation decisions which can improve air quality.

In summary, the outlook for improved consideration of air quality in transportation planning is promising, but there remains the potential for controversy and conflicting objectives. The emerging process should correct many of the problems which occurred in the past, but a great deal of work is ahead for regional, local and state agencies and officials in establishing the process and for EPA and DOT in managing it.

APPENDIX A

PERSONS AND AGENCIES INTERVIEWED

APPENDIX A

Persons and Agencies Interviewed[1,2]

City and County of Denver

William H. McNichols, Jr., Mayor
Edward Sullivan, Administrative Assistant to the Mayor

- **Department of Public Works**

  Harold V. Cook, Deputy Mayor and Manager, Public Works
  Richard Thomas, Director of Program Development
  John A. Bruce, Deputy Manager and City Engineer
  William Smith, Deputy Manager, Operations
  Robert Michael, Director of Aviation
  James Brown, Director, Traffic Engineering Division
  George Allen, Deputy Director, Traffic Engineering Division
  Edward Ellerbrock, Planning Engineer
  Larry Rehn, Traffic Safety Engineer
  Terence Searls, Traffic Design Engineer

- **Denver Planning Office**

  Gordon Appell, Planning Coordinator
  Ron Borowski, City Planning, Transportation Planning Section
  Douglas Goedert, City Planner, Central Area Section
  Wayland Walker, City Planner, Public Facilities and Environment Section
  Vernon Vanzant, City Planner, Public Information Section
  Steven Delva, City Planner Ordinance Review Section

- **Police Department**

  Robert Luby, Deputy Chief
  Al Nieto, Colorado Regional Police Safety Organization

- **City Attorney**

  George Cerrone, Assistant City Attorney

- **Zoning Administration**

  Anthony Jansen, Administrator

- **Denver Urban Renewal Authority**

  J. Robert Cameron, Executive Director
  Wayne McNanick

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[1] * indicates interview was by telephone

[2] affiliation shown corresponds to the period June, 1976 - August, 1977.

- County Court of Denver

George Manerbino, Presiding Judge

Denver Regional Council of Governments

David Klotz, Deputy Executive Director
David Pampu, Assistant Director for Planning
Larry Borger, Assistant Director for Membership Services
David Howell
Richard Krantz
Jeffrey May
Charles Mitchell*
Fred Wolfe
George Kelley
Robert Friis
John Gunyou
Gary Johnson

Regional Transportation District

John Simpson, Executive Director
John Gaudette, Executive Assistant to the Director
Ralph Jackson
David Leahy
David Apodaca
Steven Carlson
William Ettenger
Kenneth Slyziek
Linda Valdez

Colorado Department of Health

Robert Siek, Associate Director, Environmental Programs

- Air Pollution Control Commission

Laboyta Garnand, Commission Member
Val Veirs, Commission Member
Al Whatley, Commission Member
Joe Palomba, Technical Secretary

- Air Pollution Control Division

William Auberle, Director
Bruce Berger, Assistant to the Director, Budget and Program Development
Alan Stewart, Assistant to the Director for Planning and Education
Warner Reeser, Section Chief, Planning and Analysis Section
Donald Sorrels, Section Chief, Mobile Sources Section
A.C. Bishard, Section Chief, Stationary Sources Section
John Clouse, Stationary Sources Section
Ellen Hirschberg, Stationary Sources Section
Brian Iller, Mobile Sources Section
Scott Miller, Planning and Analysis Section
John Spiegel, Planning and Analysis Section

Colorado Department of Highways

Jack Kinstlinger, Executive Director
Harvy Atchison
Leonard Slosky
David Ruble
John Conger
Burrell Gerhardt
Greg Henk
Richard Brasher, Direct 6 Engineer
Joe Temple, District 6 Environmental Engineer
Lou Lipp, District 6 Traffic Engineer

Colorado Department of Commerce and Development

William Hacker

Governor's Ad Hoc Committee on Motor Vehicle Emissions

Leonard Slosky, Executive Secretary

Governor's Energy Policy Council, State of Colorado

Howard B. Gelt, Associate Director

Legislative Resource Council

Brian Mitchell

Department of Transportation, Region VIII

Robert Kessler, Secretarial Representative
George O'Rourke

Federal Highway Administration

- **Region VIII**

  Daniel Watt, Regional Administrator
  Pat Clark, Assistant Regional Administrator
  H.R. Teets, Director, Office of Planning and Research
  Donald Emerson
  Barna Juhasz

- **Colorado Division**

  A.J. Siccardi, Division Administrator
  Larry Smith

Urban Mass Transportation Administration, Region VIII

Tad Weigle, Region VIII Administrator
Leonard Lacour

Environmental Protection Agency, Region VIII

Robert DeSpain, Chief, Air Branch
John Philbrook
Charles Brinkman
Robert Doyle
David Kircher
David Wagoner
Dale Wells

Colorado State University

Jerry Gallagher, Project Manager, APCD contract
Dr. Marion Maness, Director, Mechanic Training Program
Ron Rigazzi, Project Manager, Federal EPA Contract

Denver Urban Observatory

F. William Heiss

Environmental and Related Interest Groups

- Colorado Open Space Council

Ron Lehr

- League of Women Voters

Edie Bryan
Jean Erickson
Tony Worcester

- Mountain Bicyclists, Inc.

Michael Huffager
Tom O'Hara

- Plan Metro Denver

Carla Henebry*

- Rocky Mountain Center on Environment

John Kennedy
Susan Carpenter

- **Sierra Club**

  Carla Henebry*

Vehicle Service Industry

- **Automobile Service Council of Colorado**

  Al Anderson

- **Automotive Testing Laboratory**

  Gerry Terry

- **Colorado Car Dealers Association**

  William Barrow

- **Rocky Mountain Automobile Club**

  Dan Hopkins

- **Petroleum Retailers Association**

  Al Hein

Business Interest Groups

- **Downtown Denver, Inc.**

  Phillip Millstein

- **Denver Chamber of Commerce**

  Rick Leech

- **Denver Building Owners and Managers Association**

  Robert Cohn
  Sally Stern

Real Estate Developers

- **Denver Technological Center**

  Kathy Ford
  Mary Farr
  Richard Zumm

- **Larimer Square Associates**

  Dana Crawford

Retail, Commercial and Industrial Firms

- Denver Dry Goods Company

  Carrick Hill

- Joslins

  Donald Chabot

- Neusteters

  E. Richard Auer

- J.C. Penney

  Neil Myers

- United Airlines

  Paul Griffith

- Diners Club

  Kathleen Cramme
  Linda Farrel

- Martin-Mariette Corporation

  Dr. Yumahiro*

- Conoco Corporation

  John Gehbaner*

- Statitrol, Inc.

  Rich Balducci*

- Johns-Manville, Inc.

  Rick Holden*

Financial Institutions

- Central Bank of Denver

  Eric Schmidt

- Colorado National Bank

  William C. Allen

- First National Bank of Denver

  Lynn Ricks*

- Empire Savings and Loan

  Donald Jensen
  Jon Wagner

- United Bank of Denver

  Charles Hazelregg
  Charles Luther
  Mark Swanson

Utilities

- Mountain Bell Telephone

  Will Sinton

- Public Service Company of Colorado

  Neil Allen
  James Driscoll

Consultants

- Centennial Engineering, Inc.

  Richard Sparlin
  Richard Baumann*
  Dave Baxton*

- GCA Corporation

  Allan Kasteline*
  Lane Kirkpatrick
  Ben Kincannon*

- Alan M. Voorhees & Associates, Inc.

  Steve Lockwood

- Barton-Aschmann Associates, Inc.

  Michael Powills*
  Dennis Hawker*
  Robert Scales*

APPENDIX B

REGULATION NO. 9

COLORADO AIR POLLUTION CONTROL COMMISSION

The Air Pollution Control Commission has adopted Regulation No. 9 which is intended to implement portions of the following strategies:
Regulation No. 9 follows.

(1) Improved Mass Transit,
(2) Provide Bikeways,
(7) Designation of Mandatory Bus/carpool lanes,
(8) Limitation on the construction of future parking facilities,
(9) Removal of on-street parking in the Central Business District.

Regulation No. 9

"The Control of Automotive Air Pollution Through the Encouragement of public Transportation and Motor Vehicle Restraints"

Colorado Air Pollution Control Commission

Adopted: July 25, 1974
Effective: January 6, 1975
Amended: November 13, 1975
Effective: January 30, 1976

REGULATION NO. 9

The Control of Automotive Air Pollution through Motor Vehicle Restraints and the Encouragement of Public Transportation and Carpooling

I. AREA OF APPLICATION:

This Regulation No. 9 shall apply to the Metropolitan Denver Air Quality Control Region, which includes the counties of Adams, Arapahoe, Boulder, Denver, Douglas, Jefferson, Clear Creek and Gilpin.

II. PREFERENTIAL TREATMENT OF BUSES:

A. By September 1, 1974 (in cooperation with the Denver Regional Council of Governments, the State Department of Highways and each city and county government within the Metro Denver Air Quality Control Region) the Regional Transportation District (R.T.D.) shall develop and submit to the Commission a feasibility study for demonstrating preferential treatment for buses and carpools within the Metro Denver Air Quality Control Region. By July 1, 1975, R.T.D. shall in the same manner develop and submit to the Commission a regional plan for establishing preferential treatment for buses and carpools within this region. This plan shall include implementation steps, time schedules, and costs for implementing this plan by January 1, 1976.

After the Commission holds a public hearing on and adopts the plan, each party so identified in the plan as responsible for a portion of it shall implement that portion.

In connection with the plan, R.T.D. shall demonstrate to the Division that implementation of the preferential treatment of buses will not increase the potential for additional motor vehicle traffic within the affected area.

B. By October 1, 1974, in cooperation with the Denver Regional Council of Governments, the State Department of Highways, and major local business and employment center Associations, the Regional Transportation District (R.T.D.) shall develop and submit to the Commission a plan for automobile intercept parking facilities and express bus service to employment and business centers. Said plan shall include an implementation time schedule and an evaluation of the effect of plan implementation upon reducing vehicle miles traveled (V.M.T.). After the Commission holds a public hearing and adopts the plan, each party so identified in the plan as responsible for a portion of it shall implement that portion.

C. With respect to the requirements of Sections II.A. and II.B. of this regulation, R.T.D. shall by October 1 of each year submit plan revisions and additions for improving the effectiveness of adopted plans.

III. REQUIREMENTS OF EMPLOYERS TO ENCOURAGE CARPOOLING AND OTHER METHODS OF REDUCING THE USE OF VEHICLES BY PROVIDING EMPLOYEE INCENTIVES

A. Affidavits for Carpool Locator Services and Plans for Employer Incentive Programs - Criteria, Exemptions and Certificate of Approval:

1. Affidavits for Locator Services - Criteria:

Except as otherwise provided in Section III.A.3.b., all public and private employers which employ more than fifty (50) employees at one time in any plant, building, or other business location, defined for purposes of this Section III to include such combination of facilities considered as an integral part of an entire business operation located in close proximity one to the other, shall submit to the Division, within thirty (30) days after the effective date of this Section III of Regulation No. 9, an affidavit or affidavits for each business location for which this Section III applies signed by an authorized representative of the employer and which shall provide for the following:

a. That a carpool locator service which meets the following minimal criteria, shall be implemented by the employer following the issuance by the Division of a certificate of approval of said service:

(i) That the carpool locator service be designed to match people to facilitate the transportation of two (2) or more persons per vehicle to and from work.

(ii) That the carpooling locator service provide for the designation of the "area of applicability" provided in Section I of Regulation No. 9 or such portion thereof as applicable into such geographical sections as will lend to the fullest implementation of the carpooling system on a voluntary basis while identifying the largest numbers of existing and potential carpool users both job-center and time-schedule oriented.

(iii) That the carpool locator service provide for the cross-listing among employers of less than two hundred fifty (250) people for matching carpools and carpoolers in given locales, also job-center and time-schedule oriented.

(iv) That the carpool locator service make provision for status and progress reporting as otherwise provided in this Section III on base data and effectiveness, respectively, of the program and methods of suggested improvement; or,

b. That the carpool locator service, provided by the Denver Regional Council of Governments (DRCOG) and adopted by the Commission as meeting the minimal criteria set forth in subsection 1.a. of Section III.A. above shall be implemented by the employer; or,

c. That a combination of both the carpool locator service options of subsections 1.a. and 1.b. of this Section III.A. shall be implemented, providing that such combination meets the minimal criteria stated in subsections 1.a.(i), (ii), (iii), and (iv) of Section III.A.

d. That the employer commits to maintain on a continual basis the carpool locator service or alternative thereto approved by the Division and to make available to employees readily accessible information concerning the locator service or services it is maintaining so as to enable said employees to be apprised of the services and avail themselves of them on a voluntary basis.

2. Employer Incentive Plans - Criteria:

a. The term "incentive plan" shall be deemed to be inclusive of all the incentive criteria set forth in Section III.A.2., which are deemed minimal requirements in implementing incentives to encourage the use of carpools and carpooling, bicycle use, and the use of mass transportation sources.

b. Except as otherwise provided in Section III.A.3.b., at the time and together with the submission of the affidavit required in Section III.A.1., the said employer shall also submit to the Division an incentive plan for each business location employing fifty (50) or more employees at one time, which plan shall evidence adoption, subject to Division review and approval, of minimum criteria set forth herein or such incentives as the employer deems appropriate in addition to or substitution of said criteria, which shall include the following provisions:

(i) That the incentive plan shall provide for and maintain on a continuous basis, employee encouragements without coercion, for the use of carpools, carpool locator services, bicycles and public transportation which shall include but not be necessarily limited to the provision of posted factual information regarding the value of carpooling and carpool locator service, and the posting of information as to the availability of bicylce lanes and public transportation to and from the place of employment.

(ii) Said incentive plan shall state other employer-initiated modifications, if implemented; such as free and/or reserved parking arrangements for carpooled vehicles only, provision for secure and convenient parking and/or storage of bicycles, the on-site sale of bus tickets or reimbursement of fares for the use of public transportation, adjustments in work schedules and such other means to reduce vehicle miles traveled among employees.

3. Common Provisions for Affidavits and Incentive Plans - Exemptions - Certificate of Approval:

(a) Plans and affidavits submitted by employers prior to the effective date of this Section III shall be reviewed and evaluated by the Division and approved or disapproved within ninety (90) days after the effective date of this Section. Plans submitted after the effective date of this Section III shall be reviewed and evaluated by the Division and shall be approved or disapproved within thirty (30) days after receipt of plan. If the completed submittals are approved, the Division shall issue a certificate of approval to the employer who shall post said certificate together with the affidavit and plan so as to provide notice thereof to employees. If the completed submittals are disapproved, the Division shall issue a letter of disapproval, whereupon the employer shall be given a reasonable time not to exceed sixty (60) days to revise the affidavit or plan or both in form and content acceptable to the Division. The Division shall state the reasons for such disapproval.

(b) The employer may request and, subject to approval of the Division, may be granted a waiver from any of the criteria set forth in Sections III.A.1. and A,2. or from other criteria pursuant to which a certificate of approval is issued, whether the request is made upon submittal of the affidavit and plan or after issuance of a certificate of approval. Such waiver may be granted only upon the employer having shown cause that the criteria are not applicable or are unnecessary because of circumstances unique to a business operation, or upon the employer presenting and the Division approving an alternative to any or to all the criteria providing that said alternative has the effect of measurably reducing the use of motor vehicles by employees going to and from work. Any certificate of approval based on such exemptions shall state the criteria from which the employer is exempted and the substituted criteria or alternative on the basis of which approval is granted.

B. Baseline Reporting:

In submitting the affidavit and plan, the employer shall include baseline information on forms provided by the Division, which shall assist the Division in determining transportation modes and vehicle miles traveled.

C. Annual Reporting:

All employers regulated by this Section III shall, on an annual basis coinciding with the plan submittal date, submit on a form provided by the Division, a brief progress report as to the effectiveness of implementing measures as required in this Section III.

D. Employee Inventory:

Employers of fifty (50) or more people shall supply the Division, upon request and in the manner and form prescribed by it, written evidence as to the number of people employed at one time in any one plant or other business location owned or controlled by the employer.

IV. MOTOR VEHICLE PARKING:

By March 1, 1975, the Denver Regional Council of Governments (in cooperation with the State Department of Highways and Regional Transportation District (R.T.D.)) shall provide written advice to the Commission as to the relationship, if any, between restricting the construction of new parking spaces in the Denver area and reducing vehicle miles traveled. It shall also recommend to the Commission parking requirements that may stimulate the use of public transportation and decrease single passenger vehicle miles traveled.

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APPENDIX C

TRAVEL DEMAND ANALYSIS METHODOLOGY

APPENDIX C

TRAVEL DEMAND ANALYSIS METHODOLOGY

INTRODUCTION

An integral part of the methodologies demonstrated in the Denver analysis is the set of disaggregate travel demand models used to estimate the effects of possible transportation air quality measures on work and non-work travel, and in turn, on vehicle emissions and fuel consumption. These models, and resulting travel demand forecasting system, were designed to satisfy three basic requirements. First, the models are sensitive to changes in the attributes of transportation alternatives which would result from the measures being analyzed (i.e., the models are policy sensitive). Second, the models are structured in such a way that they accurately reflect the choice process of an individual traveller deciding between travel alternatives based on the attributes of each (i.e., the models are behavioral). Third, the models represent potential second order effects on trip length, auto ownership and non-work travel as well as the intended first order impacts on work trip mode choice. Without these three conditions, a model system cannot be expected to predict the travel behavior consequences of implementing a given policy with any degree of accuracy.

The methodology utilized achieves these requirements by linking together several disaggregate travel demand models to predict auto ownership, work trip mode choice, and non-work travel demand conditional on predetermined household decisions of residential and employment location. This appendix summarizes the behavioral assumptions underlying these models, presents the set of individual disaggregate travel demand models used, goes through the prediction process for a single household, and describes the procedure used to represent various transportation policies in the model system. In addition, the steps involved in applying the model system in Denver are described. Finally, the fuel consumption submodel incorporated in the model system is presented. The vehicle emissions and air quality analysis methodology utilized is described as part of the Appendix D.

MODEL INTERRELATIONSHIPS

Two types of interrelationships are incorporated into the travel demand analysis methodology. The first of these, described as part of Chapter 11, is the time frame of a household's travel related decisions, illustrated by the solid arrows in Figure C-1. Lower level choices are made conditional on the outcome of higher level choices.

A second type of interrelationship is based on the argument that, to a certain extent, higher level choices are made based on expectations of lower level choices. For example, the choice of household auto ownership level is influenced, at least in part, by the characteristics of alternative means of travel for both work and non-work travel. These linkages from lower level choices to higher level choices are illustrated by the dotted arrows in Figure C-1 and are represented in the model system by composite variables representing expectations of the outcomes of "lower level" choices which could be different among alternatives of "higher level" choices. For example, level of service by transit for shopping trips affects auto ownership. However, this variable depends on the household choice of shopping trips, a decision which is made only conditional on the household auto ownership. Thus,

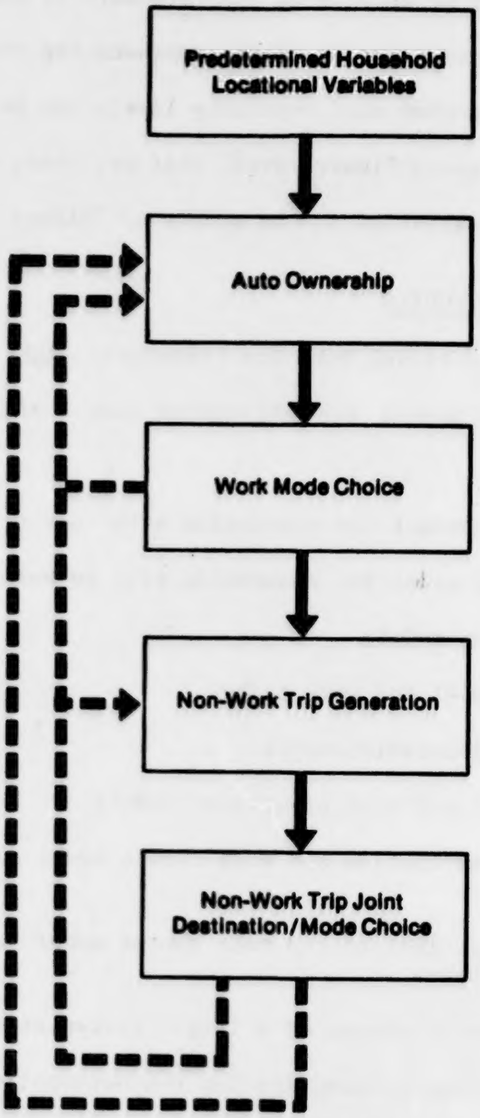
Predetermined Household Locational Variables
Auto Ownership
Work Mode Choice
Non-Work Trip Generation
Non-Work Trip Joint Destination/Mode Choice

FIGURE C-1

Interrelationships of Travel Demand Models

the specific shopping level of service is indeterminate in the choice of auto ownership. However, composite variables representing overall shopping level of service for alternative auto ownership levels can be determined. The attributes which vary among "lower level" choices, then, are aggregated and included as composite variables in the models of "higher level" choices.

DISAGGREGATE TRAVEL DEMAND MODELS

To implement the basic travel behavior framework, eight separate disaggregate travel demand models are integrated into a single model system:

1. An auto ownership model for households with one or more workers;
2. An auto ownership model for households with no workers;
3. A work mode choice model;
4. A carpool size model for work trips;
5. A shopping trip generation model;
6. A social-recreational trip generation model;
7. A simultaneous destination and mode choice model for shopping trips; and
8. A simultaneous destination and mode choice model for social-recreational trips.

These models represent a subset of a larger system of disaggregate models developed by Cambridge Systematics for the Metropolitan Transportation Commission (MTC), the designated metropolitan planning organization for the San Francisco Bay Area, using data from a 1965 Home Interview Travel Survey (1). With three exceptions, each of these models is of the multinomial logit form. The two non-work trip generation models are specified as non-linear regression models, and the carpool size model as a linear regression model. In the remainder of this section each model is briefly described in terms of its model form and dependent variables. The independent variables are summarized in Table C-1. A more detailed description of these models, including the values of the estimated coefficients, is contained in Reference 2. For a derivation of the multinomial logit model, see References 3 and 4.

1. Auto Ownership (Households with Workers) This model predicts the probability of a household with workers choosing to own zero, one or two or more autos conditional on that household's predetermined choice of residence location, housing type, and work location of the primary worker. Using the multinomial logit form, this probability is given by:

$$p(a;A) = \frac{e^{V_a}}{\sum_{i \epsilon A} e^{V_i}}$$

where p(a:A) = the probability that a household will choose to own a vehicles, excluding trucks.

V_a = linear in parameters function describing the utility of auto ownership level a. This utility is composed of household, zonal, and transportation level of service variables.

Each household has a maximum of three alternatives (i.e., 0, 1, and 2 or more autos) from which to choose. However, not every household will have all three alternatives available. In particular, households are restricted to have only those alternatives available for which their "remaining income" is positive. Remaining income is defined as household gross annual income minus dollar costs for each household member ($750 per person) and autos owned ($1,000 per auto) and the costs of work trips. One additional restriction imposed on the choice set is that households of size one cannot own two cars.

TABLE C-1

INDEPENDENT VARIABLES INCORPORATED IN TRAVEL DEMAND MODEL SYSTEM

Variables	Auto Ownership	Work Trip Mode Choice	Non-Work Trip Generation		Non-Work Destination/Mode	
			Shop	Social/Rec	Shop	Social/Rec
SOCIOECONOMIC						
Household Income	X	X	X	X	X	X
Auto Ownership/Availability	X	X			X	X
Primary Worker		X				
Number of Workers		X				
Number of Non-Workers				X		
Household Size	X	X	X	X		
Residence Type	X					
Auto Ownership Costs	X					
LEVEL OF SERVICE						
In-Vehicle Travel Time		X			X	X
Out-of- Vehicle Travel Time		X			X	X
Out-of-Pocket Travel Cost		X			X	X
Walk vs Auto Access to Transit		X				
LOCATIONAL						
Central Business District Destination		X			X	X
Employment Density	X		X	X	X	X
Employment					X	X
Population Density						X
Population						X
COMPOSITE						
Work Trip Accessibility	X					
Shop Trip Accessibility	X		X			
Social/Rec Trip Accessibility				X		

2. Auto Ownership (Households Without Workers) This model predicts the probability of a household choosing to own zero, one or two or more autos given its socio-economic characteristics and choice of residential location. This probability is given by the same multinomial logit form as the auto ownership model for households with workers. The definition of the choice set is also identical, as well as the restrictions on the availability of alternatives (i.e., positive "remaining income" and a greater or equal number of household members than autos owned).

3. Work Trip Mode Choice This model is of the multinomial logit form and predicts the probability of a worker choosing to drive alone, share a ride, or use transit (with either walk or auto access) for the home-to-work trip conditional on household residential location, auto ownership level, and employment location of the worker.[1] Not all workers will have each of these three alternatives available - workers from households with no autos are not allowed either the drive alone option or transit with auto access.

4. Carpool Size This model predicts the size of the carpool that an individual will join given that the shared ride alternative is chosen for the work trip, and is formulated as a linear regression rather than a logit function. The dependent variable is the expected value of the number of persons sharing a ride. Independent variables are disposable income and in-vehicle travel time for shared ride.

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[1] It also is possible to include vanpooling as an optional fourth mode. In this case, the same variables are considered as in the ride sharing mode, with equivalent coefficients. Level of service and other appropriate variables, however, are modified to represent vanpool conditions. In addition, the constant term is adjusted through a vanpool calibration procedure.

5. Home-Based Shopping Trip Generation This model predicts the number of daily home-based shopping trips (one way) made by a household given its residence zone and auto ownership level.[1] Unlike the models described earlier, this model is specified in the form of a non-linear regression model. The dependent variable, then, is the expected value of a continuous quantity of shopping trips rather than the probability of choosing a particular alternative from a set of discrete alternatives. A non-linear form was chosen to prevent the prediction of negative trip values regardless of the values of the independent variables.

6. Home-Based Social/Recreation Trip Generation This model predicts the number of daily home-based social/recreation trips (one way) made by a household given its residence zone and auto ownership level. This model, too, is specified as a non-linear regression and predicts the expected value of a continuous variable rather than the probability of selecting a specific alternative. Here again, the non-linear form was utilized to prevent prediction of negative trip values.

7. Home-Based Shopping Trip Destination/Mode Choice This model predicts the probability of a household choosing a particular mode/destination combination for shopping from the set of mode/destination combinations available to the household conditional on its choice of residence zone, auto ownership level, and the number of home-based shopping trips predicted by the shop trip generation model. Using the multinomial logit form, this probability is given by:

$$p(m,d:A) = \frac{e^{V_{md}}}{\sum\limits_{m' \varepsilon A} \sum\limits_{d' \varepsilon A} e^{V_{m'd'}}}$$

---

[1] Home-based trip models were developed for only three trip purposes: work, shop, and social/recreation. To account for other home-based non-work trip purposes, the home-based shop category was defined to include all home-based non-work trips other than those for social/recreation.

where $p(m,d:A)$ = probability that an individual will choose mode m and destination d from the set of d,m alternatives A

V_{md} = linear-in-parameters utility function describing the utility associated with the choice of mode m and destination d

The maximum number of alternatives available to a household is given by the product of the number of destination alternatives in the urban area times two modes - auto and transit (the destination alternatives for the Denver analysis were defined as those traffic zones having retail employment greater than zero). All households are assumed to have the auto alternative available for each destination (i.e., members of households with no autos are assumed to have the option of riding with friends or neighbors). Transit availability is based on standard transit network data.

8. Home-Based Social/Recreation Trip Destination/Mode Choice This model predicts the probability of a household choosing a particular mode/destination combination for social/recreation trips conditional on that household's choice of residence location, auto ownership, and the predicted number of trips from the home-based social/recreation trip generation model. This probability is given by the same multinomial logit form as that for the home-based shop trip destination mode choice model. The choice set definition and restrictions are also the same with the exception that available destinations are defined as having retail employment or population greater than zero.

PREDICTION PROCESS - SINGLE HOUSEHOLD

In predicting travel behavior, the demand model system proceeds through each of up to eight separate disaggregate travel demand models for one household before going on to the next household, as shown in Figure C-2. In this way, the required information on auto availability is sequentially passed downward from model to model, and the composite or accessibility variables are passed upward (denoted by dashed arrows in Figure C-2). First, the appropriate auto ownership model is used to predict the probabilities of the household choosing to own 0, 1, or 2 or more autos based on socio-economic characteristics of the household and precalculated accessibility variables from the work mode choice model and shopping trip destination/mode choice model.

The model system then loops over the remaining work and non-work models three times (once for each auto ownership level), predicting household travel behavior separately at each auto ownership level conditional on the number of autos at each level.[1] In the first loop, the work mode choice model predicts the probabilities of each worker in the household choosing to drive alone, share a ride, or use transit for the work trip conditional on the household owning no autos. Similarly, shopping trip frequency, destination and mode choice are predicted conditional on zero autos.

The linkage to the social/recreation travel models is somewhat different. Here, the work mode choice probabilities are used in conjunction

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[1] The alternative to this would be to compute the expected value for the number of autos owned and proceed through the work and non-work models only once using this single value. Use of the expected number of autos, however, is equivalent to using the mean value to represent the probability distribution of auto ownership for a household, and therefore represents use of the "naive" approach for handling aggregation. It is possible that this can introduce an aggregation bias into predictions.

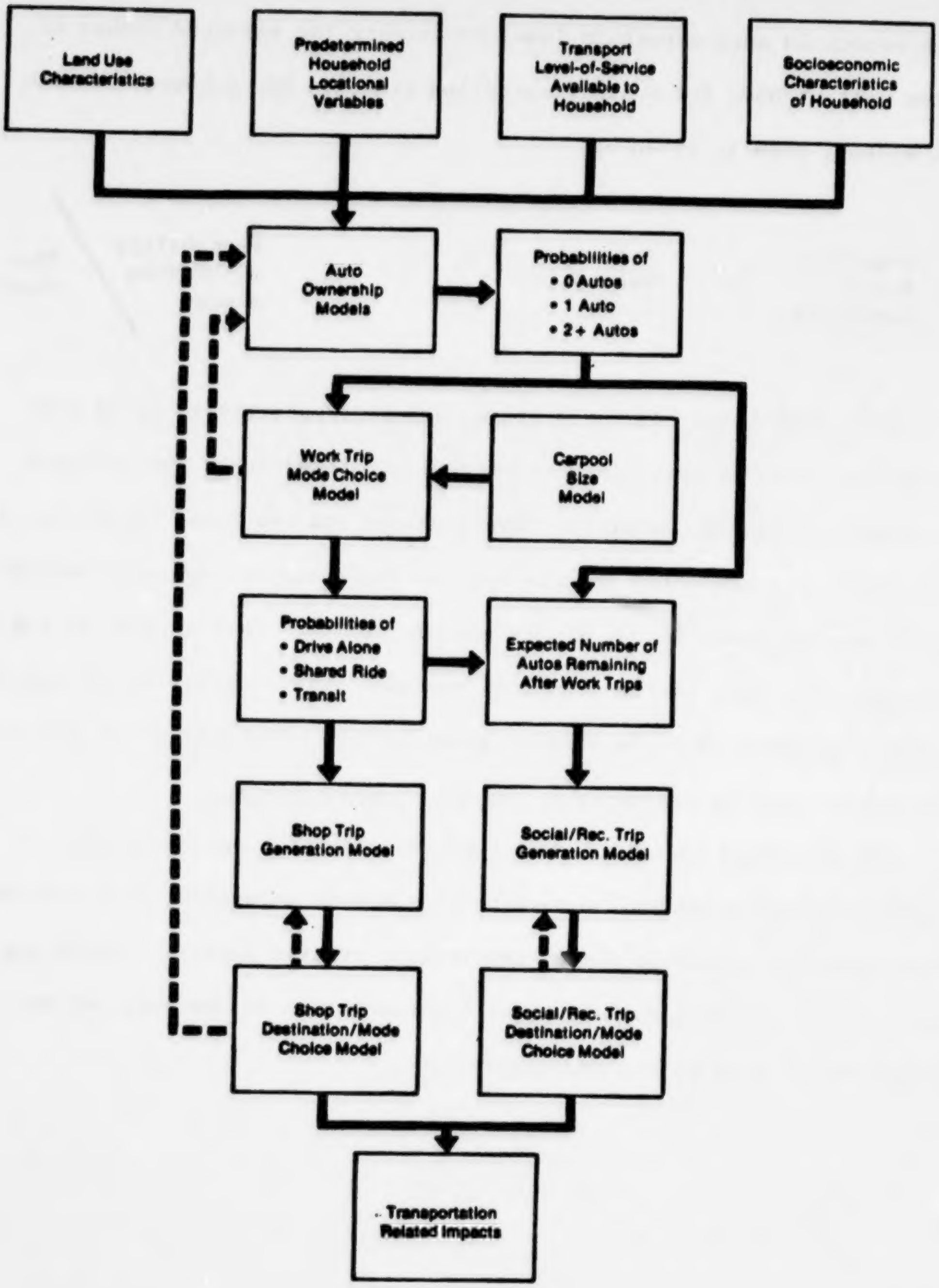
Land Use Characteristics
Predetermined Household Locational Variables
Transport Level-of-Service Available to Household
Socioeconomic Characteristics of Household
Auto Ownership Models
Probabilities of
• 0 Autos
• 1 Auto
• 2+ Autos
Work Trip Mode Choice Model
Carpool Size Model
Probabilities of
• Drive Alone
• Shared Ride
• Transit
Expected Number of Autos Remaining After Work Trips
Shop Trip Generation Model
Social/Rec. Trip Generation Model
Shop Trip Destination/Mode Choice Model
Social/Rec. Trip Destination/Mode Choice Model
Transportation Related Impacts

FIGURE C-2

Travel Demand Model Linkage - Single Household with household auto ownership level to predict the expected number of autos left at home for social/recreation travel. For a household with one worker, this is given by:

$$\begin{array}{l}\text{Expected}\\ \text{Autos}\\ \text{Remaining}\end{array} = \begin{array}{l}\text{Auto}\\ \text{Ownership}\\ \text{Level}\end{array} - \begin{array}{l}\text{Probability}\\ \text{of Driving}\\ \text{Alone}\end{array} \bigg/ \begin{array}{l}\text{Size of}\\ \text{Carpool}\end{array}$$

After predicting household travel behavior conditional on an auto ownership level of zero, this sequence is repeated twice for the same household using auto ownership levels of one and two plus. Once this is completed, the predicted results for the household at each auto ownership level are collapsed into a single set of results. This is done by taking a weighted average of the predicted household travel behavior at each auto ownership level, with the weights given by the probabilities of each auto ownership level as predicted by the auto ownership model.

The predicted household travel behavior is then passed through various impact prediction submodels (i.e.--auto emissions, fuel consumption, etc.) to predict the transportation related impacts. These impacts then are accumulated for output at the completion of the run, and the next household is read in for processing.

DATA SOURCES

In order to implement the system of disaggregate travel demand models to evaluate alternative transportation/air quality strategies, certain basic data are required:

- a randomly selected sample of households representative of the Denver region which identifies for each household, residential and employment location and selected socio-economic characteristics
- transportation level of service attributes for both peak and off-peak conditions
- selected attraction measures and other attributes of alternative destinations for non-work trip purposes (i.e., zonal level data).

For definitions of the specific variables in each of these categories and information on file structure and formats, see References (5) and (6).

The primary source of household and worker information was a home interview survey conducted in the Denver metropolitan area in 1971. From the 15,000 households originally included in this survey, 2027 were randomly selected to represent the Denver region for this analysis. These household data were updated to reflect DRCOG projections of the levels and geographic distributions of population (7) and employment (8,9), and U.S. Census projections of income (10) for the analysis years 1975 and 1985.[1] Level of service data were available in the form of auto and transit networks representing peak and offpeak conditions in 1975. For zonal level attraction measures, population, employment, and land use data were available from a study conducted in 1970. These data were updated for the 1975 and 1985 analysis years using forecasts supplied by DRCOG (9).

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[1] The procedure for updating household data, which involves the use of household expansion factors to represent changes in the distribution of selected household characteristics within the Denver area over time, is described in Reference (5).

MODEL TRANSFERABILITY TO DENVER

The basic set of disaggregate travel demand models utilized was estimated using data from a 1965 home interview survey in San Francisco. In applying these models in the Denver region, the issue of model transferability must be addressed. In theory, a strong argument can be made in support of the potential transferability of disaggregate models such as these; because these models were estimated using observed travel behavior of individuals rather than aggregate statistics, the resulting coefficients are not tied to any particular zonal system (3). Clearly, though, no model will be perfectly transferable even under the most favorable conditions. Therefore the question of transferability is more one of degree than a binary evaluation of either "transferable" or "not transferable".

Initial empirical work in this area indicated that this potential could be realized if the model was well specified (11). However, this same study also indicated that, while a theoretical basis exists for transferring the estimated relationships for travel time, cost, income, etc., no such basis exists for transferring the alternative specific constant terms, which essentially capture the effects of all other factors influencing the choice process not explicitly modelled.

Based on this, a reasonable strategy for transferring models among urban areas would be to accept the estimated coefficients for time, cost, income, etc., and adjust only the constant terms. Essentially, this is done by applying the model in the same way it is applied in forecasting. The predicted results are compared with those observed, and the constant terms are adjusted to compensate for any differences. Details of this procedure and its specific application in Denver are given in Reference (5).

MODEL REPRESENTATION OF TRANSPORTATION MEASURES

In order to predict the changes in travel behavior and related impacts associated with the implementation of air quality/transportation measures, it is necessary first to transform these measures into actual variations in the attributes of transportation services and other exogenous variables that influence travel demand. Table C-2 lists the transportation strategies analyzed and summarizes the way in which each is represented in the model system. For those strategies that can be represented by changes in the level of service variables of travel time and cost, the procedure for transforming these strategies is relatively straightforward. While this accounts for most of the strategies analyzed, some require the use of more refined representation techniques.

Employer based carpool matching and promotion programs are represented by means of a carpool incentives variable included in the work trip mode choice model. This variable, which applies only to the shared ride mode, takes the value of one if employer matching assistance and general promotion are to be provided, and zero if not. Employer based vanpool programs are represented by including vanpooling as an alternative mode in the work trip mode choice model when certain conditions of employer size and trip length are met.

TABLE C-2

Model System Representation of Transportation Measures Analyzed

STRATEGY	REPRESENTATION IN MODEL SYSTEM
I. **Employer Based Strategies**	
• Employer Based Carpool Programs	Include carpool incentives variable for shared ride alternative.
• Employer Based Carpool/ Vanpool Programs	Include carpool incentives variable, add vanpool as alternative mode.
• Preferential Parking Locations for HOV's	Increase walk time for single occupant vehicles, decrease walk time for carpools;
• Transit Fare Subsidies	Reduce transit cost for those trips affected.
II. **Parking Related Strategies**	
• Parking Tax/Surcharge	Increase auto travel cost for those trips affected.
• Parking Supply Reduction	For relatively minor reductions in parking supply, increase auto walk-time and/or travel cost to reflect the use of inconveniently located and/or more expensive parking facilities. For major reductions in parking supply, use shadow pricing in an iterative procedure to equilibrate the supply of and demand for parking.
III. **Transit Related Strategies**	
• Increase Frequency of Service	Decrease transit headways for those trips affected.
• Express Bus Service	Reduce transit in-vehicle travel time for those trips affected.
IV. **Pricing**	
• Increase Gasoline Tax	Increase auto operating costs to reflect increase fuel price
• Increase Auto Excise Tax	Increase annual auto ownership costs.
V. **Traffic Operations**	
• Improved Traffic Flow	Reduce in-vehicle travel time in travel corridors affected.

FUEL CONSUMPTION

The disaggregate travel demand models utilized in this analysis predict changes in travel behavior resulting from alternative transportation policies. An additional desired measure of effectiveness, though, is the projected decrease in fuel consumption, both area-wide and by market segment, that would be achieved by a given transportation action. Thus, an energy or fuel consumption submodel is used to translate changes in travel behavior (i.e., changes in mode choice for work trips; and changes in frequency, destination and mode choice for non-work travel) into changes in fuel consumed.[1]

The amount of fuel consumed by an auto on a particular trip is a function of several factors, including:

1) Vehicle characteristics (size, weight, engine displacement, frontal area, accessories, etc.);
2) Ambient conditions (temperature, wind speed and direction, barometric pressure, etc.);
3) Trip length/cold start;
4) Road characteristics (hills, curves, road surface, etc.);
5) Traffic flow conditions (number and duration of stops, number of acceleration-deceleration cycles, speed, etc.);
6) Driver habits; and
7) Maintenance.

For the purposes of this study, those factors considered to be of highest importance are vehicle characteristics: weight, trip length/cold start, and traffic flow.

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[1] Only changes in auto fuel consumption were considered since for most of the policies modelled, changes in transit fuel consumption would be negligible.

The remaining factors, for all practical purposes, can be assumed either to remain constant throughout the analysis or to be adequately represented by an areawide average value.

Vehicle characteristics are represented in the fuel consumption submodel by means of a set of curves relating average speed to fuel consumption rate for each of up to ten vehicle types or classes (i.e., sub-compact, standard, luxury, etc.) (Figure C-3).[1] However, because data were not available in Denver to differentiate between individual vehicle types at the household level nor was there available an appropriate disaggregate model of auto type, these curves were collapsed into a single "composite" curve for calculating fuel consumption for individual trips. This composite curve represents a weighted average of the individual curves, with the weights for each class given by the fraction of total annual VMT accounted for by each vehicle class. Changes in the areawide distribution of vehicle characteristics (a shift to smaller, more fuel efficient vehicles, for example) would be represented by altering these relationships and/or the market shares or weights assigned to each class of auto.

The effect of increased auto occupancy on fuel consumption (i.e. increased vehicle load) is represented at the individual trip level by using the results of the carpool size submodel (work trips) or average auto occupancy (non-work trips) and average trip speed together with the relationships between fuel consumption rate, inertia weight, and average speed given in Figure C-4. For example, if auto occupancy increases from

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[1] The relationship between average speed and fuel consumption rate are based on studies conducted by General Motors (12) and Union Oil Company (13).

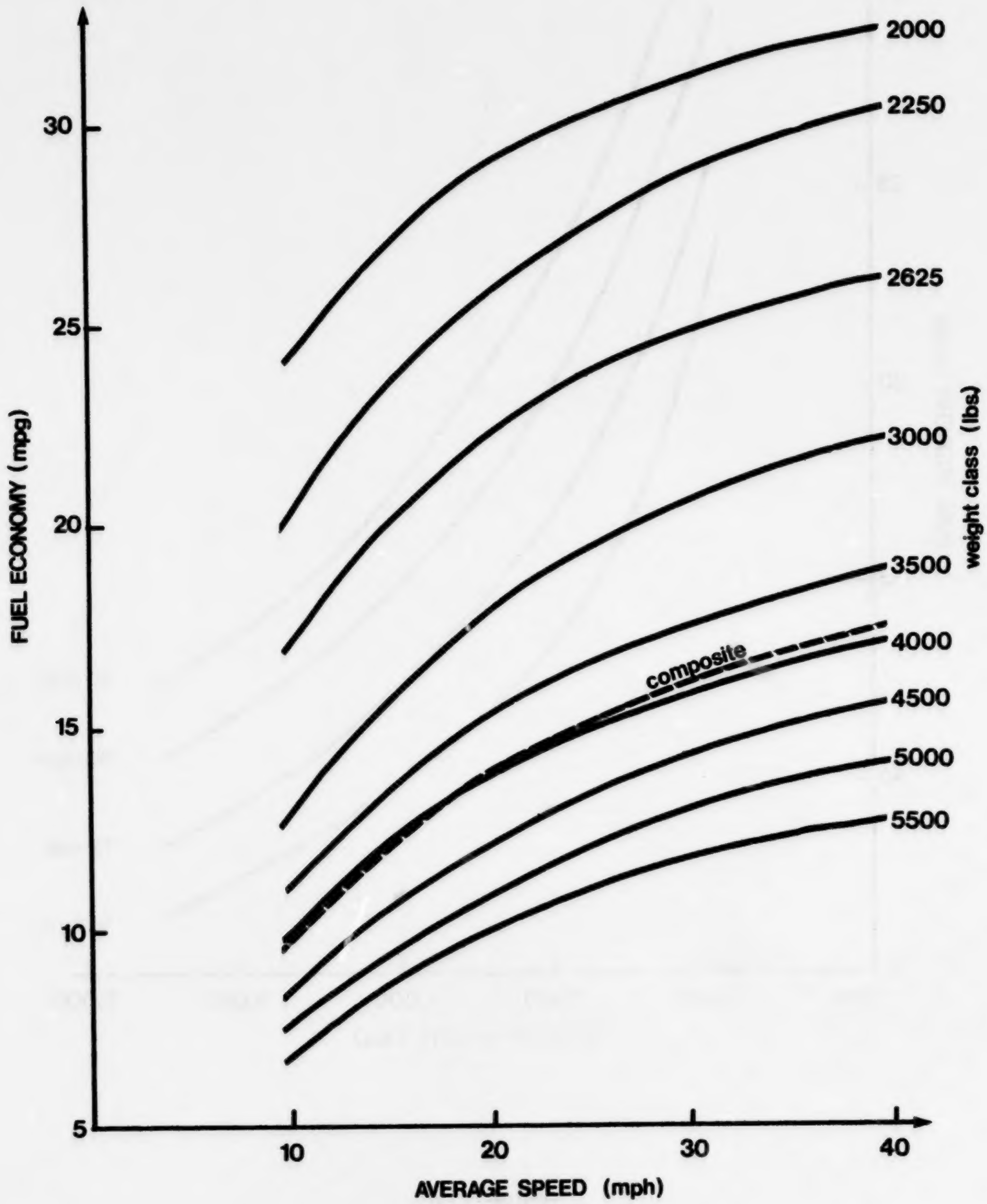


FIGURE C-3

Fuel Economy as a Function of Average Speed, by Weight Class

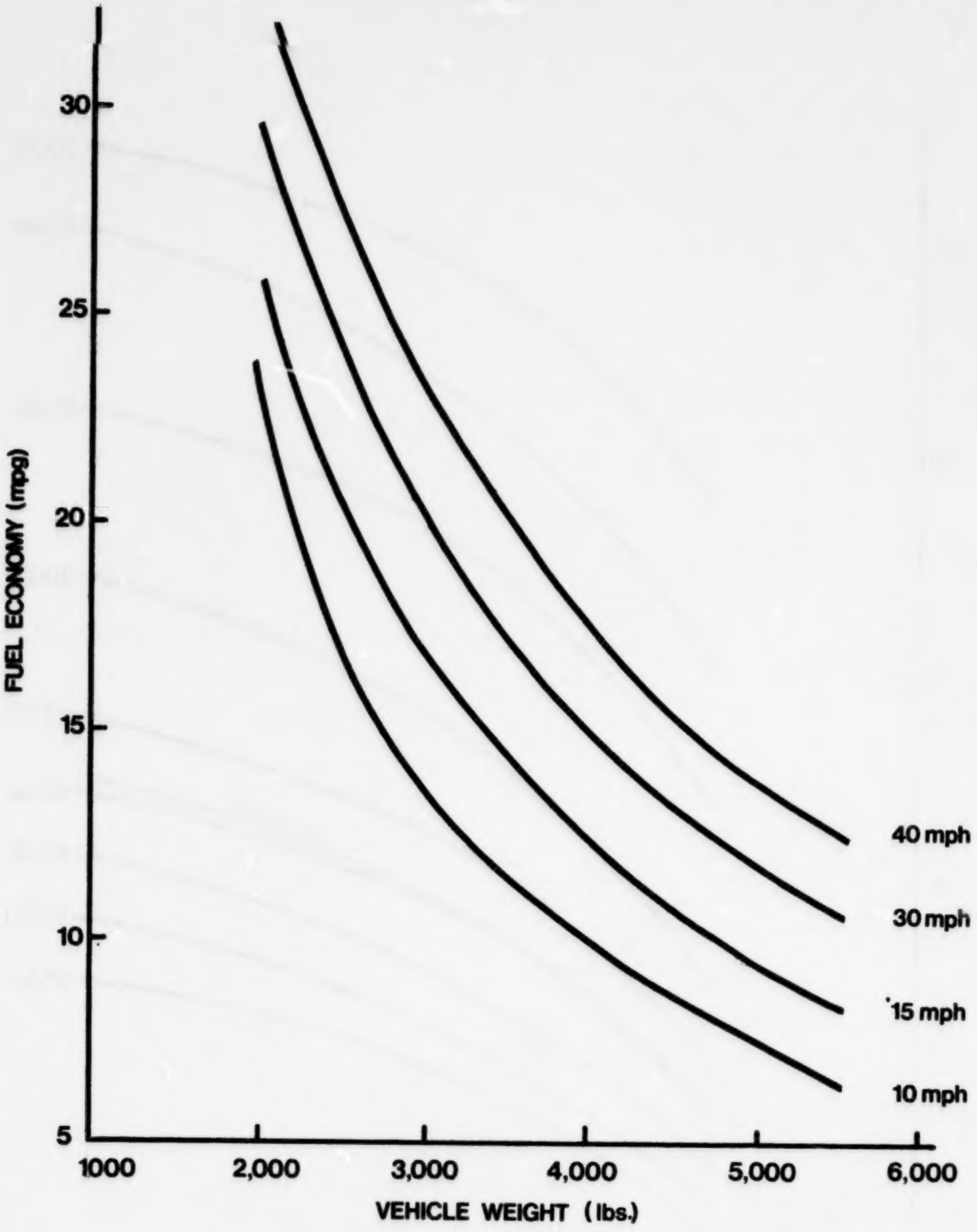
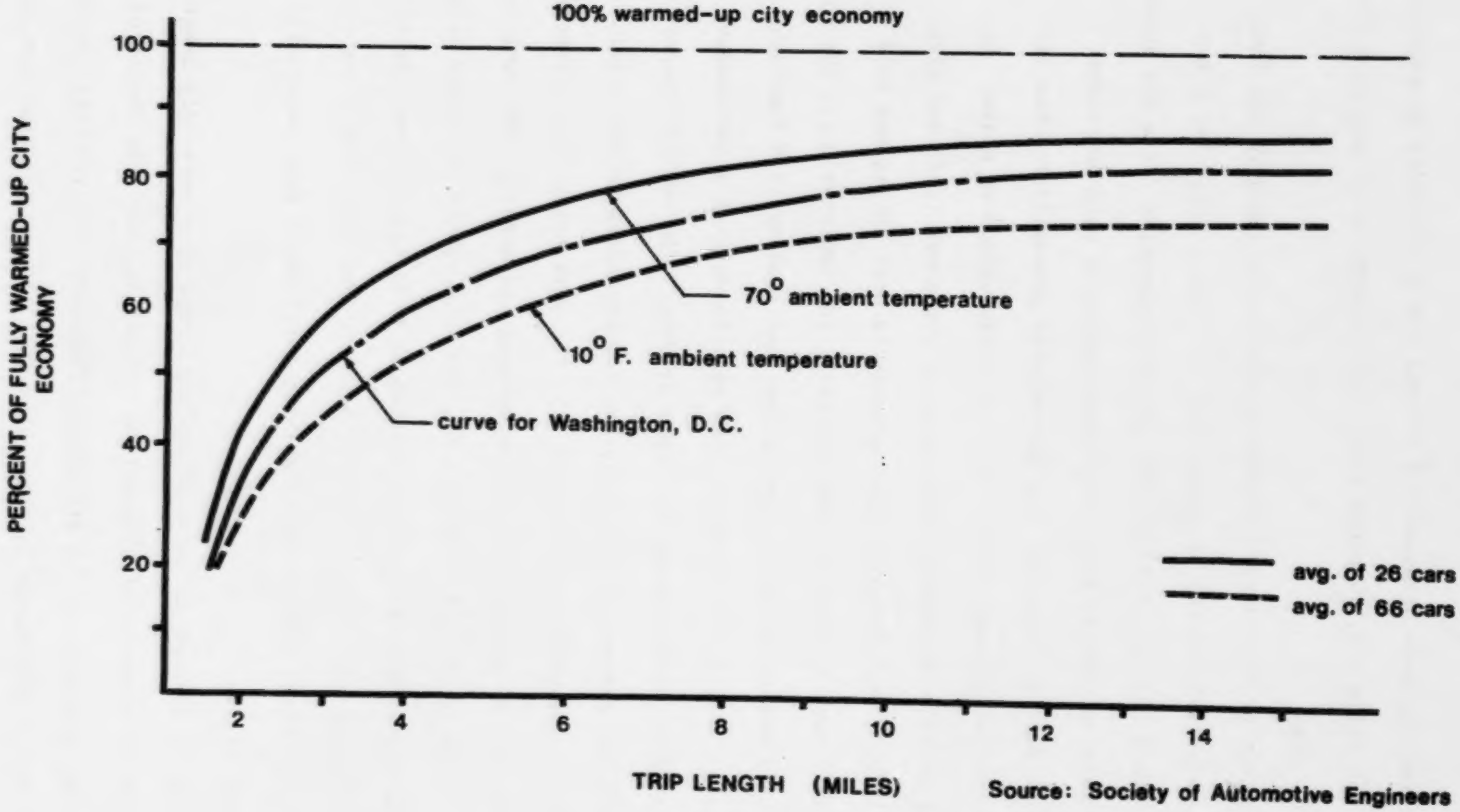


FIGURE C-4

Fuel Economy as a Function of Weight, by Vehicle Speed one to three (an increase of about 300 pounds) for a trip with an average speed of 25 mph using a 3,500 pound auto, fuel economy would decrease from 17 mpg to 15.5 mpg.

A cold start or trip length allowance also is included in the fuel consumption calculations. It is known that it takes a while for a car to warm up from a cold start if it has not been operating for a few hours. During this warm-up period, high frictional losses in cold components and lubricants must be overcome, and the vehicle gradually reaches its equilibrium operating temperature, i.e., a fully warmed-up state. Because of the frictional losses, especially in the power train and tires, thermal efficiency and therefore fuel economy is poor during the cold start. Because fuel economy is poor initially but improves until the car reaches a fully warmed-up state, cumulative fuel economy is a function of trip length. Figure C-5 displays this relationship as a percentage of fully warmed up fuel economy for urban driving. (An ambient temperature of 50°F was assumed in all analyses, corresponding to the middle of the three curves displayed in Figure C-5.) For work trips, the assumption is made that for the starts in both the morning and evening, the vehicle will be in a completely cold state (i.e., two cold starts per round trip). For non-work trips, however, the assumption is made that the vehicle will be in a cold state only for the initial start of the trip (i.e., one cold start per round trip) due to the relatively short dwell time associated with non-work trips.

While it is assumed in the analyses performed that work trip lengths do not change as a result of alternative incentives, the mode choice of various market segments may be affected differently, and the trip length/ cold start factor may result in changes in fuel consumption that are not



Source: Society of Automotive Engineers

FIGURE C-5

Cumulative Fuel Economy vs. Trip Length

directly related to VMT. For example, consider two incentives which result in equal reductions in VMT, one by eliminating a small number of long drive alone trips; the other by eliminating a large number of short drive alone trips. Based on the cumulative fuel economy relationship given in Figure C-5, the latter policy would be more effective in reducing fuel consumption, even though the reduction in total vehicles miles travelled may be equivalent.

For non-work trips, because households can choose among alternatives destinations in response to an incentive, as well as alternative modes, shopping and non-work trip lengths may vary considerably between individual analyses. Therefore, the effect of trip length and cold start on fuel consumption is more significant for non-work travel than for work travel.

The effects of transportation policies that result in changes in traffic flow conditions are represented using the relationships between fuel consumption and average speed discussed earlier. For example, if a policy is implemented that increases average speed for a particular trip from 12 mph to 15 mph (by reducing the number of stops, eliminating bottlenecks, increasing capacity, etc.), fuel economy for the composite vehicle would increase from 11 mpg to 12 mpg as shown in Figure C-3.

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APPENDIX D

AIR QUALITY ANALYSIS METHODOLOGY

APPENDIX D

AIR QUALITY ANALYSIS METHODOLOGY

Vehicle emissions and air quality estimates for various TCP measures were derived from the travel data provided by the demand forecasting methodologies described in Appendix C. This appendix describes three procedures:

- development of trip based emission estimates
- development of areawide daily emission tables stratefied by time of day and geographic district
- translation of emission effects to impacts on ambient air quality

Vehicle Emissions

Several methods for computing emissions were considered initially, including the application of an average grams-per-vehicle-mile estimate for each pollutant (derived from AP-42, (1)) to the total VMT forecast for each TCP policy. However, since the travel demand procedures computes the probability and attributes of each trip available to a household, and since emissions per mile are known to depend on specific trip characteristics (speed and time), it was desirable to utilize a method for computing the emissions for each specific trip identified in the household sample. This provides a model more sensitive to the variation in trip characteristics, and permits the classification of emission totals by trip type, household socio-economic category, origin zone, or destination zone. But the primary source of basic auto emissions data (AP-42. Supplement 5)[1] is geared to regional average estimates of auto speed, percentage cold operation and trip length, and thus, was not directly applicable to a trip-based procedure.

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[1] The work described was performed during 1976 and 1977. Supplement 8 to AP-42 was issued by EPA in 1978 and constitutes the basic source of vehicle emissions data.

Horowitz and Pernala (2,3) demonstrated a method for computing emissions for a sample of trips. Using home interview survey data from Pittsburgh and Washington, D.C., they calculated the emissions for each trip represented in the sample with the following model:

$$E_p = L[s_p(v)e_p + k_p] + \alpha c_p + h_p$$

where

E_p = emmissions of pollutant p attributable to a trip in kilograms,

L = length of trip in miles (kilometers),

$S_p(v)$ = speed adjustment factor for pollutant p and trip speed v,

e_p = running exhaust emissions of pollutant p in kilograms per mile (kilometer) averaged over the vehicle population,

k_p = crankcase emissions of pollutant p in kilograms per mile (kilometer) averaged over the vehicle population (nonzero only for HC),

α = 1 if trip begins with a cold start and zero otherwise,

c_p = cold-start emissions of pollutant p in kilograms averaged over the vehicle population, and

h_p = hot-soak evaporative emissions of pollutant p in kilograms averaged over the vehicle population (nonzero only for HC).

Total emissions for the sample were obtained from this model by summing the emissions of all trips and adding the diurnal emissions attributable to the vehicles in the sample.

Air quality data for this method were derived principally from AP-42. Running exhaust emissions were simply the average emission factors corrected for zero percent cold operation and weighted by the vehicle mix; crankcase and hot-soak emissions were taken directly from tables in AP-42.

A trip based approach very similar to that used by Horowitz and Pernala was used for the Denver analysis, based on the exact characteristics of each auto trip and each household, including:

- auto ownership (AO)
- number of trips (TNUM)
- average speed of each trip (S)
- length of each trip (VMT)
- trip time (IVTT).

The starting point for this approach is the equation provided in AP-42 for computing emissions by the Federal Test Procedure (FTP) method:

$$e_n^i = \sum_{y=y_1}^{n} (c_y^i * v_y^i * Z_y^i * r_y^i * m_y^i)$$

where: e_n^i is the emissions in grams per mile for pollutant i in analysis year n

y is the model year automobile

y_1 is the first model year considered in the analysis

c_y^i is the basic emissions in grams per mile of pollutant i for autos of model year y. Table D-1 shows high altitude values of C for 1976 and 1985, the two analysis years used in this report.

v_y^i is the speed correction factor for pollutant i and model year y. Basic emissions were measured at 19.6 miles per hour; any deviation from that speed requires an upward (for lower speeds) or downward (for higher speeds) revision. This is given by:

$V = e^{(A + B \cdot S + C \cdot S^2)}$ for CO and HC at speeds between 15 and 45 mph

$V = A + B \cdot S$ for NO_x at speeds between 15 and 45 mph

$V = A$ for low speeds

the various coefficients for the speed correction factors are shown in table D-2.

Z_y^i is the temperature correction factor for pollutant i and model year y. Basic emissions were measured at 75°F; a lower temperature requires an upward correction in the factor. Z is given

TABLE D-1

Basic High Altitude Emissions Factors

STUDY YEAR	MODEL YEAR	CO (G/mi)	HC (G/mi)	NO_x (G/mi)
1976	Pre-1968	149.0	12.30	2.00
	1968	121.0	9.70	2.86
	1969	116.0	8.40	2.93
	1970	103.0	7.80	3.32
	1971	96.0	7.20	2.74
	1972	96.0	6.70	3.08
	1973	92.0	6.20	3.70
	1974	88.0	5.70	3.50
	1975	21.5	1.76	3.20
	1976	19.5	1.46	3.10
1985	1972	120.0	9.70	3.08
	1973	120.0	9.70	5.00
	1974	120.0	9.70	5.00
	1975	39.5	3.46	4.10
	1976	37.5	3.16	4.00
	1977	16.2	2.60	2.48
	1978	4.8	0.65	1.00
	1979	4.5	0.59	0.90
	1980	4.2	0.54	0.73
	1981	3.9	0.49	0.56
	1982	3.6	0.43	0.40
	1983	3.4	0.38	0.34
	1984	3.1	0.32	0.29
	1985	2.8	0.27	0.24

Source: (1)

TABLE D-2

Speed Correction Data for the FTP Method

D-2(a): HC and CO Speed Correction Coefficients

MODEL YEAR	HYDROCARBONS			CARBON MONOXIDE		
	A	B	C	A	B	C
1957-1967	.883	$-5.58x10^{-2}$	$5.52x10^{-4}$	.721	$-4.57x10^{-2}$	$4.56x10^{-4}$
1968	.772	$-4.63x10^{-2}$	$4.80x10^{-4}$	.662	$-4.23x10^{-2}$	$4.33x10^{-4}$
1969	.706	$-4.55x10^{-2}$	$4.84x10^{-4}$	.628	$-4.04x10^{-2}$	$4.26x10^{-4}$
1970	.840	$-5.33x10^{-2}$	$5.33x10^{-4}$	.835	$-5.24x10^{-2}$	$4.98x10^{-4}$
Post-1970	.787	$-4.99x10^{-2}$	$4.99x10^{-4}$	.894	$-5.54x10^{-2}$	$4.99x10^{-4}$

D-2(b): NO_X Speed Correction Coefficients

MODEL YEAR	A	B
1957-1967	.602	$2.027x10^{-2}$
1968	.642	$1.835x10^{-2}$
1969	.726	$1.403x10^{-2}$
1970	.614	$1.978x10^{-2}$
Post-1970	.697	$1.553x10^{-2}$

D-2(c): Values of A for Low Average Speeds

MODEL YEAR	CARBON MONOXIDE		HYDROCARBONS		NITROGEN OXIDES	
	5 mi/hr	10 mi/hr	5 mi/hr	10 mi/hr	5 mi/hr	10 mi/hr
1957-1967	2.29	1.48	2.34	1.37	1.33	1.20
1968	2.43	1.54	2.10	1.27	1.22	1.18
1969	2.47	1.61	2.04	1.22	1.22	1.08
1970	2.84	1.72	2.35	1.36	1.19	1.11
Post-1970	3.00	1.83	2.17	1.35	1.06	1.02

Source: (1)

TABLE D-3

Temperature Correction Coefficients

CONTROL TECHNOLOGY	CARBON MONOXIDE		HYDROCARBONS		NITROGEN OXIDES	
	A	B	A	B	A	B
non-catalyst	1.95	-.0127	1.81	-.0113	1.36	-.0046
catalyst	6.58	-.0743	3.25	-.0304	1.52	-.0060

Source: (1)

by: $Z = A + B \cdot t$. The coefficients for the speed correction factors are shown in table D-3.

r^i_y is the cold operation correction factor for pollutant i and model year y. Basic emissions are measured for a "typical" trip with 20% cold operation (representing the first 505 seconds of a trip); greater cold operation entails an upward adjustment, while lower cold operation requires a downward adjustment. r is given by:

$$r = \frac{w + (100 - w) \cdot f(t)}{20 + 80 \cdot f(t)} \quad \text{for non-catalyst-equipped vehicles}$$

and

$$r = \frac{w + x \cdot f(t) + (100 - w - x) \cdot g(t)}{20 + 27 \cdot f(t) + 53 \cdot g(t)}$$

where w is the percentage cold operation
x is the percentage hot start operation
f(t) is given by $f(t) = A + B \cdot t$ for all non-calalyst vehicles and for NO_x and HC for catalyst vehicles; $f(t) = e^{A + Bt}$ for CO in catalyst-equipped vehicles
g(t) is given by $g(t) = A + B \cdot t$ for HC and NO_x and by $g(t) = e^{A + B \cdot t}$ for CO.
Values of A and B are shown in table D-4.

m^n_y = proportion of travel in study year n by vehicles of model year y. This is commonly computed for (a) the proportion of vehicles in the fleet from each model year and (b) the average VMT for vehicles of each model year. The 1976 and 1985 Denver data are summarized in Table D-5.

The basic variables necessary for applying this equation on a trip-by-trip basis are available from the travel demand forecasting system described in Appendix C. Speed is directly available from the internal transportation data, and percentage cold operation may be obtained using EPA's average of 505 seconds (8.417 minutes) cold operation per trip (% cold operation = $w = \frac{8.417}{IVTT} \times 100$). But the number of computations per trip would be very large if it were necessary to enumerate each term of the equation for each trip. Fortunately, temperature and vehicle age distributions are constant for all trips in a given analysis, and this fact can be used to simplify the computation considerably.

TABLE D-4
Coefficients for the Cold Operation Correction Factor

POLLUTANT	CONTROL TECHNOLOGY	g(t)		f(t)	
		A	B	A	B
CO	non-catalyst	-	-	.02	.0045
	catalyst	-5.24	.035	-4.14	.0360
HC	non-catalyst	-	-	.03	.0079
	catalyst	.0095	.0018	-.0409	.0050
NO_x	non-catalyst	-	-	1.64	-.0068
	catalyst	.858	-.0010	.835	.0010

Source: (1)

TABLE D-5

Derivation of Model Year Weighting Factors

MODEL YEAR	PROPORTION IN POP.	AVERAGE MILES	M*	MODEL YEAR	PROPORTION IN POP.	AVERAGE MILES	M*
1976	.052	14600	.085	1985	.073	14600	.104
1975	.068	13300	.101	1984	.119	13300	.154
1974	.096	12100	.130	1983	.113	12100	.119
1973	.106	11000	.131	1982	.108	11000	.106
1972	.105	10000	.118	1981	.096	10000	.103
1971	.086	9100	.088	1980	.088	9100	.087
1970	.081	8200	.075	1979	.080	8200	.069
1969	.081	7400	.067	1978	.071	7400	.066
1968	.071	6700	.053	1977	.061	6700	.054
1967	.059	6100	.040	1976	.059	6100	.039
1966	.057	5600	.036	1975	.036	5600	.028
1965	.048	5200	.028	1974	.039	5200	.022
pre-1965	.090	4700	.047	1973	.031	4900	.024
				pre-1973	.031	4700	.025

*computed as

$$\left[\frac{(\text{PROP. in POP})_y \times (\text{AVG. MILES})_y}{\sum_{y=y_1}^{n} (\text{PROP. in POP.})_y \times (\text{AVG. MILES})_y} \right]$$

Source: (4), pages 3-4 and 3-6.

Daily Emissions

The following is a brief summary of the sequence in which CO, HC, and NO_X trip based emissions are combined with hot-soak and diurnal hydrocarbons to estimate total household daily emissions.

1. For each household, compute the diurnal hydrocarbon emissions using household auto ownership data.
2. For each trip:
   a. Determine average trip speed, speed interval, and cols start factor, and temperature correction factor
   b. Compute tailpipe CO, HC and NO_X emissions per vehicle mile
   c. Multiply each emission factor by the trip VMT
   d. Add hot-soak hydrocarbon emissions per trip to the HC emissions total.
   e. Weight trip emissions by the trip probability
   f. Add weighted trip emissions to any desired analysis totals (e.g. total emissions by pollutant, emissions by trip purpose, etc.)
3. Add the weighted emissions for all trips to obtain household emission totals.
4. Add the household diurnal HC emissions to the household HC emission total.
5. Add household emissions to any desired cumulative totals.

In order to examine the geographic distribution of pollutant emissions such as would be required in a CO hotspot analysis, trip based emissions can be accumulated into a zone-by-zone "trip table" corresponding to the traffic zone system being used in the analysis[1]. For each policy analysis, up to six "origin-to-destination" emission tables can be developed:

- by pollutant type
  CO, HC, NO_X

---

[1] These zonal based tables can be aggregated into district level tables, if desired, containing a smaller number of matrix entries, e.g., a 10 by 10 or 5 by 5 table.

- by trip purpose
    - work trips
    - non-work trips (shopping and social-recreational

Ambient Air Quality

The outputs of the trip-based procedure consist of "base case" emission totals for each of the three major pollutants, and percentage changes from the base case for various TCP measures and groups of measures under consideration. A simple comparison of the measures based on emissions reductions provides useful information about air quality effectiveness, but the most important air quality consideration is the degree of improvement in ambient pollution levels likely to result from implementation of the measures. The emissions changes do not tell us this directly.

A number of methods are available for converting emissions predictions into estimated ambient levels. The method chosen for use in this study is a variation of the "rollback" model, which was the approach originally recommended by EPA for determining the percentage reduction in VMT necessary for achievement of the ambient standards. As adapted for this application, the rollback model assumes that the percentage change in ambient pollutant level is equal to the percentage change in total emissions for that pollutant. Given the known ambient concentration in the base year (annual average or second-highest day, depending on the basis for the applicable standard), the fraction of the total pollutant burden emitted by private autos, and the estimated percent change in auto emissions (resulting from a given TCP option), the new ambient concentration is estimated in the following way:

1. Multiply the estimated percent change in auto emissions and the fraction of total pollutant burden emitted by autos to get an estimated percent change in total emissions.
2. Multiply the estimated percent change in total emissions by the base year ambient concentration to get the estimated change in ambient concentration.
3. Subtract the estimated change in ambient concentration from the base year ambient concentration to get a revised ambient pollution level.

Application of this procedure in the case of hydrocarbons, carbon monoxide, or nitrogen oxides is straightforward, but not so for ozone, which is an atmospheric by-product of HC and NO_x. For ozone, it is necessary first to compute the revised ambient pollution levels for HC and NO_x in the above manner, and then to convert these estimates to the expected ozone level using the graph shown in Figure D-1

The Denver data necessary for these computations are contained in Table D-6.

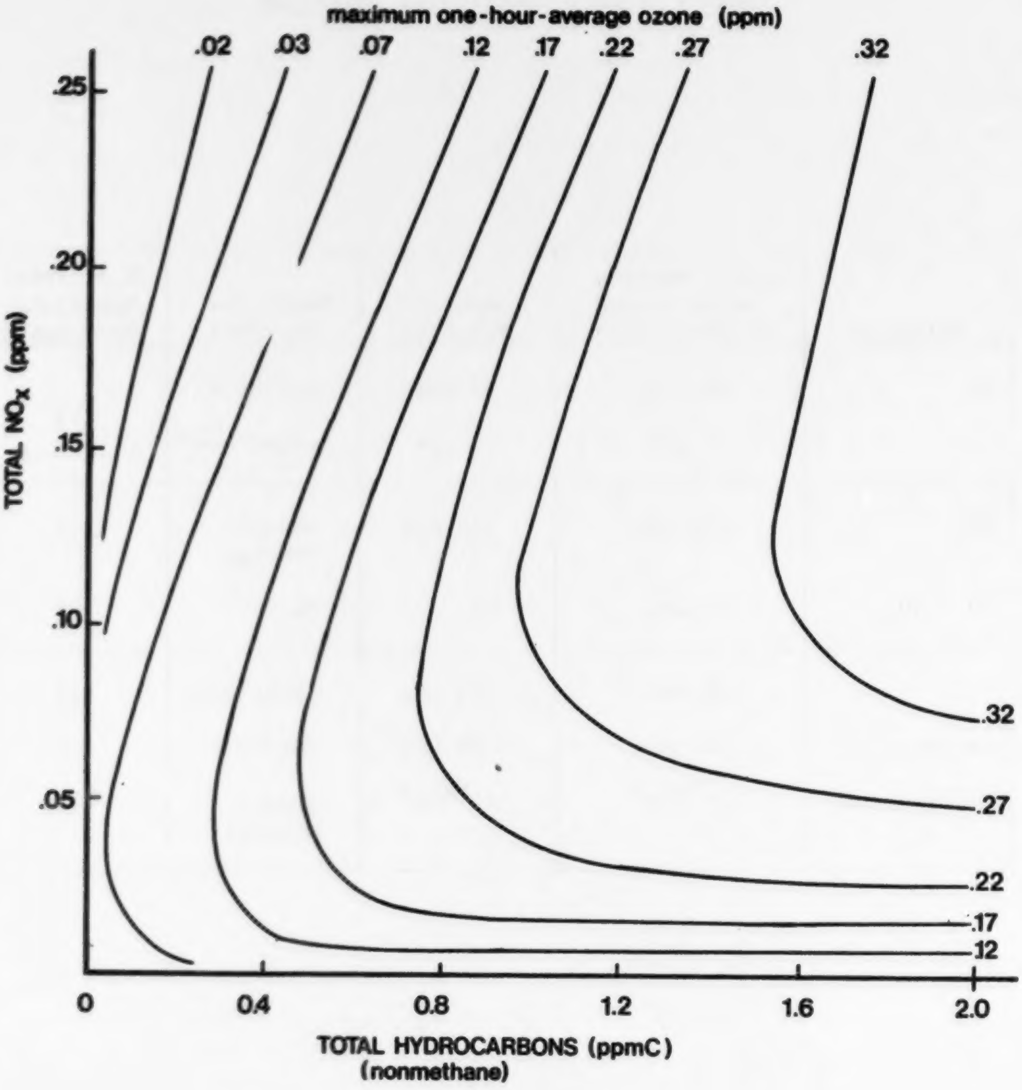

FIGURE D-1

Graph of Denver SAI Air Quality Model Results

Source: (5)

TABLE D-6

Summary of Auto Contributed Emissions

Pollutant	1976 Ambient Level Second Highest Day*	Ambient Standard	Basis for Standard	% of Total Emissions From Autos
CO	68 ppm	35 ppm	one-hour	73
	31 ppm	9 ppm	eight-hour	
NO_2	.056 ppm	.05 ppm	annual average	--
$NO + NO_2$	.06 est.	NA	NA	32
HC	.38 est.	.24 ppm	three-hour	55
Oxidants	.141 ppm	.08 ppm	one-hour	--
Particulates	$225^{Mg}/_{M^3}$	$44^{Mg}/_{M^3}$	annual average	10

*Figures used in this column are 1975 predictions from the SAI model.

Source: (5)

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APPENDIX E

INDIRECT ECONOMIC ANALYSIS METHODOLOGY

APPENDIX E

INDIRECT ECONOMIC ANALYSIS METHODOLOGY[1]

AGGREGATE MODEL

The aggregate model is a cross-section regression that estimates retail sales in different parts of the metropolitan area as a function of market characteristics such as access to households, household income, and noon-hour shopping by nearby workers. An important objective of this methodology has been the use of readily available data, so that costs of data collection would be minimal. Therefore, the specification of the regression has been chosen to conform with data originally assembled for the Denver EMPIRIC activity allocation model. Individual observations in the regression are the geographic zones defined for use with the EMPIRIC model.

The focus of the model is on estimating the sensitivity of sales to changes in access between customers and stores. For each retail zone, the accessibility to households throughout the metropolitan area was defined for the EMPIRIC model as

$$A_i = \sum_{j=1}^{N} H_j \cdot f(t_{ij}) \qquad [1]$$

where A_i is the accessibility of stores in zone i to households, N is the total number of zones, H_j is the number of households in zone j, t_{ij} is travel time between i and j, f( ) is the travel impedance function[2]. The form of the impedance function is the gamma function .

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[1] A more complete discussion of the aggregate and disaggregate models, and of the analysis results obtained is provided in Reference (1).

[2] Several previous works have developed accessibility models of retail sales (2, 3, 4). The work of Lakshmanan and Hansen uses accessibility to distribute the retail expenditures of consumers in a zone to retial stores in that and other zones. The model developed here uses accessibility to explain directly the total retail sales of different zones. Lakshmanan's earlier work has the same objective as the model developed here, but the specification of his model is quite different.

$$f(t_{ij}) = \frac{b^a}{\gamma} t_{ij}^{a-1} e^{-bt_{ij}} \qquad [2]$$

The stores in zone i do not operate in isolation but in competition with retailers in all other zones in the metropolitan region. Their competitive position depends not only on their accessibility to potential customers but also on the access of competitors to this market. It is useful, therefore, to introduce a slightly modified accessibility measure for retailers in each zone. This modified measure, which has been named competitive accessibility, is simply the access to customers of stores in zone i divided by the average of access measures for all competitive zones:

$$\frac{A_i}{\bar{A}_j} = \frac{A_i}{(1/N)\sum_{j=1}^{N} A_j}, \; i \neq j \qquad [3]$$

Because of arbitrary variations in zonal retail sales caused by variations in zone size, the dependent variable has been defined as sales per zone acre. The estimated relationship between sales and competitive access takes the form

$$S_i^* = \alpha_0 \left(\frac{A_i}{\bar{A}_j}\right)^{\alpha_1} \qquad [4]$$

where S_i^* is sales in zone i per zone acre. If all zones were equally accessible, sales in each would be α_0. The coefficient α_1 measures the elasticity of sales with respect to changes in competitive accessibility.

Equation [4] implicitly assumes full adjustment of sales to current levels of accessibility. To satisfy this assumption, retail centers must have expanded in areas where access to households has recently increased and contracted where access has recently declined. Households must have adjusted shopping patterns in favor of centers that have become more accessible to them and those where growth in size has created greater shopping opportunities. Such adjustments typically take many years. New stores are not opened immediately, nor existing ones closed, in response to changes in demand. Households continue to be governed by shopping habits acquired in the past. These lags in adjustment can be explicitly modelled, so that

$$S_i^t = \left(\frac{S_i^*}{S_i^{t-1}}\right)^{\beta} \cdot S_i^{t-1} \qquad [5]$$

where S_i^t is current sales, S_i^* is fully adjusted sales, and S_i^{t-1} is sales in the past period. Current sales depend upon the relative size of fully adjusted sales and last period sales and upon β, which measures the fraction of the disparity that is closed in the current period. If, for example, $\beta = .4$ and fully adjusted sales are 10% above those achieved in the past, current sales will rise by 4%.

Substituting [4] into [5] and taking logs,

$$\log S_i^t = \beta \log \alpha_0 + \beta\alpha_1 \log\left(\frac{A_i}{\bar{A}_j}\right) + (1-\beta)\log S_i^{t-1} \qquad [6]$$

Equation [6] shows the basic form of the regression model, which can be easily estimated by linear regression techniques.

The model actually estimated for Denver is somewhat more complex. To measure the separate effects of auto and transit accessibility on retail sales, measures of each are included separately as explanatory variables in the regression equation. Both of the accessibility variables are of the form just described. They differ from one another in numerical value because of differences in travel times by car and by bus.

As indicated at the beginning of this section, several variables other than access to households are likely to be important in explaining variations in retail sales. These variables are included in the regression to control roughly for forces operating simultaneously with accessibility to determine retail sales, rather than to provide precise measures of their impacts. Therefore, the form of their appearance in the regression has been determined by the requirement that they be easily available from the EMPIRIC data set and that they be compatible with the equation shown in [6]. Careful specification of functional form is not as important for these variables as for accessibility, for which precise measures of impact are the principal objective of the study.

Because sales depend not only on accessibility to households but on level of income in the most accessible markets, income in these markets is the first control variable. For each retail zone, it is measured by the fraction of households in the zone with incomes in the lowest 15% of the regional income distribution. The second control, which accounts for the impact of noon-hour shopping by white collar workers, is the number of service, government, finance, insurance, and real estate workers in the zone. Because this number can vary arbitrarily with zone size, the variable has been defined as white collar workers per zone acre.

With one exception, all variables discussed so far are available for

1960 and 1970 directly from the EMPIRIC data set. The exception is the volume of retail sales. The EMPIRIC data measures retail activity by retail employment rather than retail sales. However, sales per employee can be calculated for different parts of the Denver region from data in the Census of Retailing. For parts of the region outside the CBD - Adams, Arapahoe, Boulder, Jefferson, and the rest of Denver - sales per employee are relatively constant in different places. In the CBD, they are considerably lower than in the rest of the region. To estimate sales in each zone, zonal retail employment, from the EMPIRIC data set, was multiplied by sales per employee. Employment in the CBD has been converted using the Census estimate of CBD sales per employee. Employment in other zones has been multiplied by the average sales per employee for the rest of the region. Census figures for 1963 have been used to convert the 1960 EMPIRIC employment data; 1967 Census numbers have been used for the 1970 employment data.

The sales equation used for empirical analysis is

$$\log S_i^t = \beta\log\alpha_0 + \beta\alpha_1\log(\frac{C_i}{\overline{C}_j}) + \beta\alpha_2\log(\frac{T_i}{\overline{T}_j}) + \delta_1\log Y_i + \delta_2\log W_i + (1-\beta)\log S_i^{t-1} + e \qquad [7]$$

where

$\frac{C_i}{\overline{C}_j}$ = competitive access to shoppers travelling by car

$\frac{T_i}{\overline{T}_j}$ = competitive transit access

Y_i = the proportion of households in i with incomes in the lowest 15% of the regional income distribution

W_i = number of white collar workers in i per zone acre

e = a random, standard normal error.

Empirical results are shown in Column 1 of Table E-1. All coefficients are significantly different from zero (.01 level) with the expected signs, except for transit access, which is both insignificant and incorrect in sign. Because there are no plausible circumstances in which improved transit access should reduce retail sales, the combination of incorrect sign and statistical insignificance argues strongly that the true effect of transit on sales is zero. Therefore, the equation has been reestimated without transit access as an explanatory variable, a procedure that constrains its coefficient to be zero. The results are shown in Column 2.

The Column 2 results can be used to measure the elasticity of sales in any zone with respect to changes in travel time for shoppers with cars. Using the notation of Equations [4] - [7], α_1 is a measure of the elasticity of sales with respect to auto access; the coefficient of auto access is $\beta\hat{\alpha}_1$; and the coefficient of last period sales is $(1-\hat{\beta})$.[1] Since $\hat{\alpha}_1 = \widehat{\alpha_1\beta}/[1-(1-\hat{\beta})] = .271/.415$, the elasticity of sales with respect to auto access is .653. Auto access itself is a function of travel time as shown in [2]. If the a, b, and γ parameters estimated for the EMPIRIC model and the 1970 travel times of shoppers driving to the CBD are substituted into [2], a 10% increase in these times leads to a decrease of 15.6% in auto accessibility, for an elasticity of -1.56. The elasticity of sales with respect to auto travel time is, therefore, .653 x -1.56 = -1.02, for an increase in time in the neighborhood of 10%.

The empirical results also provide a measure of the speed of adjustment to changes in the determinants of retail sales. This speed is

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[1] ^ indicates an estimated value.

TABLE E-1

Aggregate Model of Retail Sales (1970), Empirical Results

Variable	(1)		(2)	
	Coefficient	t-ratio	Coefficient	t-ratio
Auto Access (1970)	.327	3.09	.271	2.82
Transit Access (1970)	-.081	-1.25	-	-
Income Level (1970)	-.330	-2.92	-.351	-3.15
White Collar Workers (1970)	.209	3.82	.200	3.68
Last Period Sales (1960)	.598	13.34	.585	13.38
Constant	3.424	-	3.238	-
R^2	.834		.833	
Observations	153		153	

measured by β_1 which can be estimated from the coefficient of last period sales. According to the model, if current market conditions imply equilibrium sales 10% above those of ten years ago, 41.5% of the full adjustment will have occurred over the decade, so that sales will have risen 4.15% during that time.

DISAGGREGATE MODEL SYSTEM

The disaggregate methodology for estimating indirect economic impacts both utilizes and extends the set of travel demand models described in Appendix C. Using the random sample household simulation of travel behavior decisions as a basic analytic framework, a disaggregate model of work based shopping trips is combined with the two home based shopping models described in Appendix C to produce estimates, by subarea, of changes in shopping trips and retail employment in response to changes in the transportation system.

Basic Model Structure

In this set of models, retail employment activity is treated as being simultaneously determined with people's shopping choices. It is derived from some of the basic Lowry model concepts, but involves a much more sophisticated set of models than has been used previously.

The entire model system is depicted in Figure E-1. In this diagram, there are two different sources of shopping trips, home-related and work-related. As used in this context, home-related shopping trips include those trips which are part of tours that begin or end at home but may visit more than one retail store. Similarly, work-related shopping (e.g., lunch hour trips) may also include multiple stop tours.

There are two relatively intuitive features of the model system. First, where retailers choose to locate and/or expand their activities depends on how many people will shop there; second, the decisions of individuals about where to shop are influenced by the level of service provided by the transportation system to various centers and the scale of retail activity at each center.

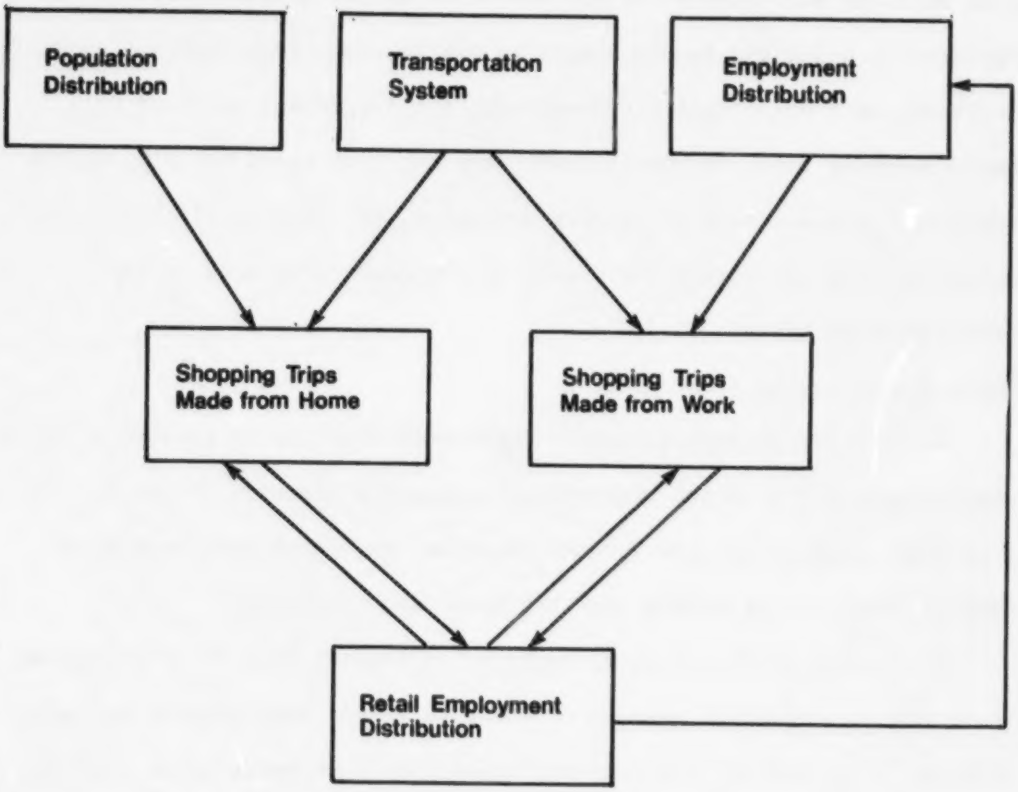
Population Distribution
Transportation System
Employment Distribution
Shopping Trips Made from Home
Shopping Trips Made from Work
Retail Employment Distribution

FIGURE E-1

Structure of Disaggregate Model System

Home Based Shopping

The two home-related shopping trip models are the same as those described in Appendix C:

- a non-linear regression model of shopping trip frequency
- a joint multinomial logit model of shopping trip destination and mode choice[1]

As defined in Appendix C, the models include variables relating to household size, income, retail and service employment densities, auto ownership, travel time and cost by mode, and CBD location. A critical linkage between the two models is provided by including in the frequency model an accessibility variable which includes all of the level of service and socioeconomic variables appearing in the joint destination/mode choice model. Its inclusion makes the frequency of shopping travel, as well as destination and mode, responsive to changes in transportation policy. For each household, the frequency and destination/mode choice models together predict the number of shopping trips and, given the utility offered by each destination/mode alternative, the probability each alternative will be chosen for any trip.

Originally estimated for the San Francisco area, the home-based shopping models have been partially recalibrated so as to match base year Denver travel conditions. The models were run using 253 households sampled from the 1971 Denver Home Interview Survey. A total of 274 zones were used in forecasting (aggregated from the existing Denver traffic zone system), though all results have been summarized at the level of 10 super zones. The downtown Denver area was considered as a single super zone in the analysis.

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[1] Because retail employment is endogenous in this particular application rather than being exogenous as in normal transportation forecasting, this model was re-estimated with an unconstrained coefficient for retail employment. To achieve a property of zonal homogeneity in the original model, the coefficient of retail employment had been constrained to unity.

Since the model predicts only home-based trips, it was necessary to assume some average number of shopping visits per home-based trip. Downtown Denver merchants consistently estimated an even split between visits to stores by home-based shoppers and visits by downtown workers on noon-hour trips. The model estimated an equal number of home-based and noon-hour work-based trip ends if an assumption of two shopping trip ends per home-based trip was made. These additional visits were assumed to take place in the same superzone as the home-based link of the trip tour.

Work Based Shopping

The second source of shopping trips represented in the model is noon-hour shopping by workers. To forecast noon-hour trips, a model of downtown shopping trips originally developed for a study of the Bunker Hill area of Los Angeles was adopted (Barton-Aschman Associates/Cambridge Systematics, 1975). Because the noon-hour model was originally estimated only for workers in the CBD and because noon-hour shopping is generally considered an important fraction of total sales only in the CBD, the model of work-based trips was applied only to Denver's downtown zones.

This model is also a joint multinomial logit. However, unlike the home-based shopping models, in which the frequency and destination/mode models are distinct (though linked through the accessibility variable), the work-related shopping model treats trip frequency, mode and destination in a single model. Basically, the model is analogous to the shopping mode/destination choice model, except that an extra alternative, that of not travelling at all, is available to all travellers.

The model does not use the socioeconomic characteristics of workers, since such data is unlikely to be readily available in forecasting. For this reason, the model can be used on a zonal basis, rather than using a sample of travellers. It predicts the number of workers in each CBD workplace zone who will travel by each mode to each CBD shopping destination as a function of the utility offered by each alternative, including that of not making a trip. The modes considered are auto, walk, mimibus or downtown circulator, and normal bus. Variables included are total travel time, travel cost for auto, a trip attraction density, and the employment density at the origin zone.

As with the home-related shopping trip model, some number of shopping visits per shopping tour is needed to compute the total shopping trip ends for any single zone. Evidence from Los Angeles suggests 1.25 shopping trip ends per work-based shopping tour. As with the home-related trip model, the extra shopping visits that comprise the tour are assumed to be made in the same superzone as the work-based trip.

Equilibration Procedure

In any single policy test, the first step of the equilibration procedure is to modify the level of service variables reflecting the effect of the policy on the transportation system in Denver and to apply both the home-based and the downtown work-related shopping trip models to forecast the total shopping trip ends for each zone. These results are then aggregated to the 10 superzone level.

The predicted shopping trip ends in each superzone is then computed as a percentage of the base year value. The percentage change in retail employment is assumed to be equal to the percentage change in shopping trip ends. This results in a new level of both total and retail employment, which are then input into both the home-based and the work-related shopping trip models. The resulting trip end forecasts are then used to further revise retail and total employment, and the process is iterated until the change in retail employment for each zone is relatively small.

Mathematically, this procedure can be expressed as follows: Let R_i and E_i be the retail and total employment in zone i, respectively. Suppose that R_i^o and E_i^o are the initial values in the base year. Finally, let $T_i(R_i, E_i)$ be the total trip ends as forecast, and T_i^o be the base year shopping trip ends for zone i.

The entire process can be expressed in the following algorithm.

Step 0: Initialize R_i^o and E_i^o. Adjust level of service to reflect policy under consideration. Set $R_i = R_i^o$; $E_i = E_i^o$

Step 1: Use home-based and work-based shopping models to forecast $T_i\ (R_i, E_i)$ for all i

Step 2: For each i, compute

$$R_i' = \left(\frac{T_i}{T_i^o} \right) R_i^o$$

$$E_i' = E_i - R_i + R_i'$$

Step 3: If $\frac{R_i' - R_i}{R_i}$ is small then stop. Otherwise, set $R_i = R_i'$, $E_i = E_i'$ and go to Step 1.

Trial runs of several iterations of the model indicated that, for many different policy options, the change in trips at each iteration was a constant fraction of the change at the previous iteration. Given this pattern of convergence and a first round change in trips of ΔT_i, the total change can be approximated by

$$\Delta T_i + \alpha \Delta T_i + \alpha^2 \Delta T_i + \alpha^3 \Delta T_i + \ldots =$$
$$\Delta T_i \sum_{j=0}^{\infty} \alpha^j = \frac{\Delta T_i}{1-\alpha}$$

where α is the ratio relating changes in trips at successive iterations. The total change in trips is a measure of the change in demand at retail center i. Since the analysis assumed

$$\frac{\Delta R_i}{R_o} = \frac{\Delta T_i}{T_o}$$

where ΔR_i is the initial change in retail employment, the corresponding total change in the size of the retail center is given by

$$\frac{\Delta T_i \left(\frac{R_o}{T_o} \right)}{1 - \alpha}$$

This approximation greatly reduces the number of iterations required to operate the entire model system, since ΔT_i is computed at the first iteration, and a reasonable estimate of α can be obtained in two or three iterations. This approximation was used for all policy analysis.

It must be noted that the exact mathematical properties of the iterative equilibration procedure are still unknown and that the limited computational experience obtianed in this study is insufficient to reach any definitive empirically based conclusion about the model's stability. Trial runs that led to the approximation adopted above indicated some instability in α after the first several iterations, and changes in the definition of zones and superzones affected the pattern of convergence. The model system, however, has a strong conceptual appeal, and further research into its properties is definitely warranted.

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APPENDIX F

METHODS OF CORRECTION FOR ANNEXATIONS

APPENDIX F

METHODS OF CORRECTION FOR ANNEXATIONS

All data on recent economic and demographic changes in the City and County of Denver have been reported in the text for the area within the city's 1960 boundaries. As explained in the text, analysis of economic and demographic change requires constant boundaries so that this change is not hidden by changes in geographic definitions. Since data are commonly reported for current rather than constant boundaries, some adjustments have been necessary. This appendix discusses the technique for making those adjustments.

The total 1970 and 1975 population within the city's 1960 area has been reported by the Denver Planning Office in its "1980 Population Forecast.[1] These total population figures have been used to adjust all other economic and demographic data. For example, before adjustment for annexations, the population of the four county region is split so that 514,678 lived in the city in 1970 and 583,231 lived in the suburbs. Holding boundaries constant at their 1960 limits, the division is 474,162 in the city and 623,747 in the suburbs. These numbers imply that the population of the suburbs in 1970 would have been 6.95% greater if no annexation had occurred. Other 1970 data have been adjusted from current to constant boundaries by assuming that the number of high income families, low income families, and jobs in the suburbs would also have been 6.95% greater in 1970 if no annexation had taken place.

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[1] These numbers are different from estimates of population within the city's boundaries reported in other sources, including U.S. Bureau of the Census, 1970 Census of Population, Characteristics of the Population, Colorado, Table 8. Correspondence with the Denver Planning Office identified the numbers used here as the correct figures.

This procedure probably understates the appropriate job connection, since jobs tend to be more highly clustered around the city than population.[1] If jobs are more concentrated than population in central areas, and annexed areas are parts of the suburbs closest to the city, holding boundaries constant would cause the number of suburban jobs to increase by a greater percentage than the number of suburban residents. For jobs, therefore, this connection procedure represents a conservative estimate of the number of city jobs gained by annexation rather than growth within constant boundaries. Similar procedures and similar comments apply to the 1975 adjustments. Both adjusted and unadjusted data are shown in Table F-1.

Adjustments to the journey to work data, shown in Table F-2, embody similar methods, although they have been based on five county rather than four county data. Without annexations, suburban population of the five county region would have been 755,647 rather than 715,131, an increase of 5.67%.[2] To adjust the journey to work data, a similar percentage increase has assumed for workers living in the suburbs and for workers traveling to suburban jobs. For workers both living and working in the suburbs, the connection factor has been applied twice: first, to account for an increase in suburban residents in the absence of annexations; then, to account for an increase in suburban jobs.

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[1] This clustering is evident, for example, in Table F-1. For any definition of the city's boundaries, it contains a much larger fraction of metropolitan jobs than metropolitan population. Likewise, density functions estimated by Mills for Denver show that the number of jobs per square mile drops off much more rapidly with distance from the center than population per square mile. This rapid drop means that jobs are much more concentrated in and around the center (Edwin S. Mills, "Urban Density Functions," Urban Studies, January, 1970, Table 1).

[2] Source for this computation is U.S. Bureau of the Census, 1970 Census of Population, Characteristics of the Population, Colorado, Tables 9 and 14; Denver Planning Office, "1980 Population Forecast," January, 1976.

TABLE F-1

Economic and Demographic Data
Central Area, City and County of Denver, Balance of Four County Region*

CENTRAL AREA [a]

	1960	1970	1975
Total Population	140,904	121,447	113,520
High Income Families	12,155	8,171	-
Low Income Families	19,732	17,600	-
Employment-COG(CBD)	-	61,000	72,000

CITY AND COUNTY OF DENVER
(Including Central Area)

	1960	1970		1975	
		Unadjusted	Adjusted	Unadjusted	Adjusted
Total Population	493,887	514,678	474,162	527,100	456,000
High Income Families	70,901	66,540	59,787	-	-
Low Income Families	53,734	60,786	57,416	-	-
Employment - Census	245,918	294,028	283,748	-	-
- COG	-	305,000	292,323	350,000	326,896

BALANCE OF FOUR COUNTY REGION

	1960	1970		1975	
		Unadjusted	Adjusted	Unadjusted	Adjusted
Total Population	361,242	583,231	623,747	776,800	847,900
High Income Families	58,127	97,169	103,922	-	-
Low Income Families	32,378	48,483	51,853	-	-
Employment - Census	84,427	147,911	158,191	-	-
- COG	-	182,400	195,077	252,500	275,604

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*For both 1960 and 1970, low income families are those whose income places them in the lowest 40 percent of the family income distribution for the four county region. High income families are in the upper 60 percent of the distribution.

[a] Central Area is defined in text. For employment data, study area is the CBD.

Sources of Unadjusted Data:

1960 Population and Income: U.S. Bureau of the Census, *1960 Censuses of Population and Housing, Census Tracts*, Denver, Colorado SMSA, Table P1.

1960 Employment*: U.S. Bureau of the Census, *1960 Census of Population*, *Subject Reports*, *Journey to Work*, Tables 1 and 2.

1970 Population and Income: U.S. Bureau of the Census, *1970 Census of Population and Housing*, *Census Tracts*, Denver, Colorado SMSA, Tables P1 and P4.

1970 Employment (Census)*: U.S. Bureau of the Census, *1970 Census of Population*, *Subject Reports*, *Journey to Work*, Tables 1 and 2.

1975 Population (Central Area): Denver Planning Office, "1980 Population Forecast," January 1976.

1975 Population (Denver and Rest of Four County Region): Denver Regional Council of Goverments, "DRCOG Regional Development Plan, Policy Population Forecast Subarea Population Allocation," August, 1976, Table 2-11.

1970 and 1975 Employment (COG): Denver Regional Council of Governments, unpublished memorandum, "Suburban Employment Methodology," March, 1977.

1970 and 1975 Population within 1960 Boundaries of Denver: Denver Planning Office, "1980 Population Forecast," January, 1976.

*1960 and 1970 Census employment figures have been computed by using data on the place of employment for residents of the Denver SMSA shown in Table 1 of the Census *Journey to Work* volume, and on the number of workers living outside the SMSA who worked in each of the SMSA's constituent counties, shown in Table 2. Data for SMSA residents includes data on those who did not report place of work. These workers have been allocated to workplaces in the same proportions as those who did specify their workplaces. Total employment for each county is simply the sum of SMSA residents, after allocation of non-reporters, and non-residents working in that county.

TABLE F-2

Number of Daily Work Trips[a]

	1960		1970		1975	
			Unadjusted		Adjusted	
	Total	Transit	Total	Transit	Total	Transit
Total	330,366	32,117	454,190	19,847	454,190	19,847
Work in Denver	229,238	30,662	272,682	17,635	262,390	17,510
Work in Suburbs	101,128	1,455	181,508	2,212	191,800	2,337
Live in Denver	182,744	28,115	194,012	15,728	179,260	15,494
Live in Suburbs	147,622	4,002	260,178	4,119	274,930	4,353
Work in Denver						
Live in Denver	165,723	27,429	163,730	15,005	156,321	14,730
Live in Suburbs	63,515	3,233	108,952	2,630	106,069	2,780
Work in Suburbs						
Live in Denver	17,021	686	30,282	723	22,939	764
Live in Suburbs	84,107	769	151,226	1,489	168,861	1,573

[a] Worktrips either beginning or ending outside the SMSA are excluded. Worktrips with place of work not reported are also excluded.

Sources: U.S. Bureau of the Census, *1960 Census of Population, Characteristics of the Population*, Colorado, Table 131.

U.S. Bureau of the Census, *1970 Census of Population, Characteristics of the Population*, Colorado, Table 190.

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APPENDIX G

DESCRIPTION AND ASSESSMENT OF DENVER REGIONAL AIR QUALITY MODEL

APPENDIX G

DESCRIPTION AND ASSESSMENT OF DENVER REGIONAL AIR QUALITY MODEL

The SAI Model

A photochemical oxidant model developed by Systems Applications,Inc., (SAI) is being used by the Colorado Department of Health and others to simulate air quality conditions in the Denver metropolitan area. The SAI model predicts pollutant concentrations as a function of time and location, taking into account atmospheric transport and chemical reactions. The model is based on the numerical solution of coupled time-dependent mass conservation equations. It allows for wind convergence and divergence and elevated inversion behavior. Six pollutants, reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2, NO_3, and CO are considered, and both motor vehicles and stationary sources are included.[1] The chemical reaction rates used in the model are determined from a 15-step kinetic mechanism.

Emissions from automobiles and fixed sources (including airport operations) are combined to produce an array of total pollutant fluxes into each one square mile ground level grid cell contained in a 30 x 30 mile modelling region for Denver. Hourly wind and mixing depth maps are prepared for each grid cell by interpolating from available wind measurement and inversion soundings. The airshed simulation uses the emissions and meteorology to yield the spatial and temporal distribution of pollutants.

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[1] Specifically, the model has been used to predict CO and O_3 concentrations; however, all six species are included in the chemical reactions in the model. The Colorado Department of Health's Climate Dispersion Model was used to obtain annual average NO_2 and particulate pollutant concentration estimates for the Denver area.

Transportation, Land Use, and Air Quality Inputs

Inputs to the SAI model include the following:

- a development plan, including population and activity distribution patterns;
- a transportation network;
- traffic volumes assigned to links; and
- network speeds, including both average operating speeds and peak hour speed corrections.

The sources of these inputs are shown in Table G-1.

TABLE G-1

Land Use and Transportation Inputs to SAI Model

INPUT	SOURCE
Development Plan	Adopted JRPP[1] Land Use Plan (2000)
- subarea details	EMPIRIC Cycle 3 (1980, 1985, 2000)
Transportation system	For 1980:
- highway networks	Denver Functional Classification System
	For 1985:
	Outer Route Network - 1980 System Plus I-470
	For 1990: Same as 1985 (see volumes, below)
	For 2000: Adopted JRPP Highway Plan
Network volumes	Trip generation, distribution, and mode split:
	cross-classification for home-based trip productions
	linear regression for all other trip type productions
	linear regression for all trip attractions
	utility-based mode split curves
	gravity models for trip distribution (transit and highway distributed separately, by time)
	Traffic assignment: for highways- LOADVN for 1975 and 1980 (unrestrained assignment
	UROAD for 1985, 1990, and 2000 (capacity unrestrained assignment)
	for transit- ULOAD
Link speed	Average operating speeds by functional classification and area type (adjustments to UROAD)

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[1] Joint Regional Planning Program

The air quality data needed for the SAI model are emissions data and meteorological data, as summarized in Table G-2.

TABLE G-2

Air Quality Inputs to SAI Model

INPUT	SOURCE
air quality standards	EPA regulations and Clean Air Act, as amended
vehicle emission factors	AP-42, Supplement 5 (EPA)
emissions from stationary sources	Colorado Dept. of Health (large point, small point, area, and airport)
meteorological data	monitoring of weather conditions: specific data measured on two days: November 15, 1974 July 29, 1975
air quality monitoring data for the study days	CO: CAMP Station, (November) O_3: Overland Park Station (June)

Surface wind station measurements were interpolated to provide a two-dimensional wind field, taking into account topographical features such as the Platte River basin. Wind speeds were assumed to be the same aloft, since no data on upper-level wind speeds were available. Inputs on inversion heights, mixing layer depths, vertical temperature profiles, and solar radiation also were obtained.

The one-hour CO concentration on the November day, as measured at the CAMP station, was 25.7% of the worst hour for the year (29.5% of the second highest hour) and 42.0% of the eight-hour maximum (45% of the second highest eight-hour period). The one-hour ozone maximum on the June day, measured at the Overland Park station, was 75.4% of the worst hour (77.0% of the second worst).

Model Operation

The model couples emissions, transport (meteorology) and chemical reactions to estimate concentrations of pollutants over the region. Added to the emissions and meteorology inputs described above are methods for estimating inversion heights and vertical diffusion. The chemical reactions which occur are extremely complicated and are not fully understood (hundreds of reactions are known or postulated to occur), and the chemical kinetic mechanism used in the model represents a compromise between detail and computational efficiency.

Calibration of the model was accomplished using two days' monitoring data to determine the relationship between measured and predicted concentrations. The winter day was used to calibrate for CO and the summer day for ozone. Adjustment factors to correct the concentrations predicted for the monitoring days to the concentrations actually measured were developed. These factors then were used to adjust the model simulations of future air quality conditions.

The highest one-hour CO concentration predicted by the model for Nov 15, 1974 at the CAMP station was 30 ppm; the actually measured second highest day at CAMP was twice as high, 61 ppm. Assuming that the highest violations generally occur in the same part of the region and that the meteorology will be similar, it also can be assumed that the factor of two between prediction and measurement will remain valid. Therefore, a factor of two was used to adjust the one-hour CO concentration predictions The same approach was used to arrive at a factor of 1.8 for predicting the eight-hour average CO concentrations for future years.

For ozone, however, maximum concentrations do not alwasy occur in the same part of the region, and so assumptions like those used for factoring CO predictions are not reasonable. Therefore, data from the study day, which was the 22nd worst day, was used to predict the second worst day.

Square miles of violation are estimated by multiplying the predicted concentration by the probability of violation, derived from the standard deviation which is implicit in the kinetic model.

Assessment

It is widely agreed that the Denver simulation model of air pollution concentrations represents the state of the art as of 1977. However, it also should be clear that the model's output is highly dependent upon a large amount of input data and on several simplifying assumptions. That is, the air quality estimations can only be as good as the transportation and land use modelling outputs, the weather data and the methods used to treat those data, and on the kinetic mechanism. Specific sources of uncertainty in the Denver modelling system thus include the following:

1) AP-42, Supplement 5 data, whose adequacy for high altitudes has been questioned;

2) emissions inventory and projections accuracy;

3) JRPP population, land use, and activity inputs, where significantly different projections exist (note that EMPRIC Cycle 3 has since been abandoned);

4) transportation network and traffic characteristics, where the adopted plan is being restudied;

5) meteorological data, where available data were limited and assumptions had to be made to fill the gaps;

6) the kinetic mechanism simulation adequacy in representing poorly understood and complicated chemical reactions;

7) study days and the methods used to estimate second-worst concentrations, which require many untested assumptions.

All of these factors combine to make it risky to assume that the model predictions are accurate, not because of deficiencies in the model, but because of accumulated uncertainties from the series of predictions which must be made.

APPENDIX H

URBAN AIR POLLUTION AND HEALTH EFFECTS

APPENDIX H

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URBAN AIR POLLUTANTS

Air quality became a matter of federal concern in the 1950's, but air pollution already had been recognized as an aesthetic and health problem for many years. The coincidence of high death rates and heavy pollution episodes in industrial cities such as London and Pittsburgh did not pass unnoticed, nor did the increasingly heavy smogs which enveloped Los Angeles as growth and auto travel jumped in the post-war years. On their own initiative, these severely impacted areas undertook steps to cut down on pollution by controlling the sources and establishing programs of research on the episodic and long-term effects of human, animal and plant exposure to heavy pollutant concentrations. The Federal interest was recognized in 1956 when Congress passed legislation to initiate a national program of research(1).

As evidence of severe health effects mounted, and auto-related smog spread to cities all over the country, the need for greater Federal involvement became apparent. The Air Quality Act of 1967 (2) established ambient air standards for the major air pollutants and funded a full-scale program of further research in the Department of Health, Education and Welfare to determine the appropriate levels for ambient air standards to protect the general health, but left implementation of the standards entirely to the states. Reluctance of the states to impose restrictive standards on themselves led finally to the Clean Air Act Amendments of 1970 (3), which empowered the newly-formed Environmental Protection Agency to establish national health-related ambient air standards and to supervise their attainment. The EPA conducted tests on humans and animals to ascertain whether and how much pollution in ordinary urban air can have a detrimental effect on human health. Maximum air pollution levels were determined that would ensure the health of the general public, and these became the national ambient air quality standards (Table H-1).[1]

The EPA standards cover six major contaminants: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_X), photochemical oxidants (primarily ozone), sulfur oxides (SO_X), and particulates. The following sections briefly describe the sources, health effects, and standards for the first four of these.[2]

Carbon Monoxide

It is commonly known that carbon monoxide is a principal component of auto exhausts. It results when insufficient oxygen is present during combustion so that fuel is not completely burned. The amount of CO can be reduced by increasing the air/fuel ratio, but complete control of CO production in an auto engine is difficult to achieve because combustion is uneven (i.e., the air/fuel mixture is not evenly distributed within the combustion chamber). When the combustion process is easily controlled, as in a larger boiler, CO production can be reduced to an insignificant level. Thus, automobiles are by far the primary source of CO.

Carbon monoxide is a heavy molecule which remains close to the ground and near to the emission source until air movement disperses it. Dense concentrations of CO can accumulate at intersections where the sheer volume of pollutant released exceeds the dispersion capability of natural venti-

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[1] The standards are set to protect normally healthy people from either short-term or cumulative harm. People with poor respiratory or cardiovascular health may still be adversely affected by air that meets the national standard.

[2] Neither particulates nor oxides of sulfur present a serious auto related pollution problem in Denver, and thus these pollutants are not discussed here. Denver does have serious particulate pollution, however, to which autos make some small contribution.

TABLE H-1

National Ambient Air Quality Standards

Pollutant	Ambient Standard	Basis for Standard
CO	35 ppm 9 ppm	one-hour eight-hour
HC	.24 ppm	three-hour
NO_2	.05 ppm	annual average
Oxidants	.08 ppm	one-hour
Particulates[1]	260 mg/m^3 75 mg/m^3	twenty-four hour annual average
SO_2	.14 ppm .03 ppm	twenty-four hour annual average

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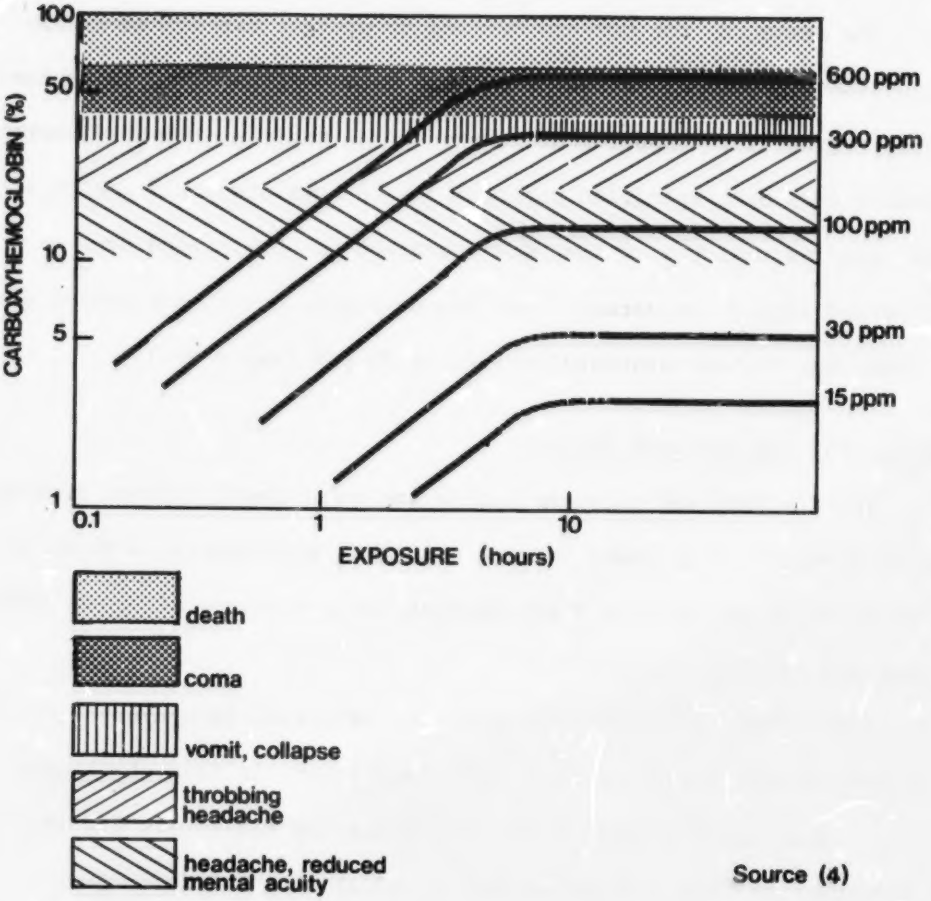
[1] Colorado ambient standards for particulates are 45 mg/m^3 for one-hour and 150 mg/m^3 for twenty-four hours.

lation, and in urban "canyons" surrounded by tall buildings. The atmosphere has a relatively high level of natural CO so ambient concentrations quickly approach natural levels as the pollutant disperses. Nevertheless, high concentrations may be sustained over a wide area if there is a dense street network and heavy traffic.

CO can have severely toxic effects in high concentrations, progressing from mild headache, to coma, and eventually to death. But these effects occur only after prolonged or intense exposure. For example, 5 hours at 100 parts per million will produce headache and reduced mental acuity (in a normally healthy adult), while even a short exposure at 1000 ppm could result in death. The highest sustained concentrations ever recorded in an urban setting were in the range of 40-50ppm (Chicago; 1962-1963) (4), well below the level of severe effects, but auto occupants and pedestrians may be exposed to concentrations of 100 ppm or greater for shorter periods.

The toxicity of CO stems from the way in which it hinders oxygen transport to the cells. It readily substitutes for oxygen on the hemoglobin molecule (to form carboxyhemoglobin), thereby decreasing the supply of oxygen to body tissues and increasing the cardiac effort necessary to maintain the oxygen supply. The effects of various levels of carboxyhemoglobin on the body of a normal adult and their relationship to CO exposure are shown in Figure H-1. At levels approaching 7%, a healthy adult may experience impaired cognitive function, reduced manual dexterity, decreased auditory and visual sensitivity, and increased heart rate at all levels of exercise. These same effects on susceptible individuals - pregnant women, those with lung or heart disease, and the elderly - are accentuated and occur at lower exposure levels and blood concentrations. Because of the increased heart activity necessitated by CO, the rate of



Source (4)

FIGURE H-1

Response of Healthy Adults at Light Activity to Various Carbon Monoxide Exposures heart attacks may rise for those with cardiovascular disease.

EPA's Office of Research and Development has estimated the number of cardiac deaths and the number of days of disability per year resulting from different ambient levels of CO, Table H-2. While these figures are subject to great uncertainty and might be considered high or low by different experts, they are included as one indication of the aggregate effect of CO pollution.

EPA standards for CO were defined to prevent carboxyhemoglobin levels from exceeding 2% at any time as a result of exposure to ambient concentrations. The standards are expressed as maximum allowable average concentrations over specified periods. The "8 hour standard" for CO is 9 ppm, meaning that the ambient concentration of CO averaged over an 8 hour period should not exceed 9 ppm for more than one 8 hour period during the year. The "1 hour standard" for CO is 35 ppm (Table H-1).

Hydrocarbons and Nitrogen Oxides

Hydrocarbons and nitrogen oxides are the primary factors contributing to photochemical smog. Under intense sunlight, they undergo a chain of reactions which may produce heavy ambient concentrations of ozone, nitrogen dioxide and oxidized hydrocarbons.

Hydrocarbons originate in vehicular exhausts, in non-exhaust vehicular emissions such as fuel tank evaporation, or from stationary sources - especially petrochemical facilities. Approximately 55% of all hydrocarbons come from automobiles, and another 26% from other "mobile sources". Most of the auto-related emissions are a by-product of combustion in the engine. Incomplete combustion produces partially oxidized hydrocarbons, and as with CO, non-uniformities within the

TABLE H- 2

Impacts of Exposure to Carbon Monoxide

CO Mean Concentration*	Standard Deviation of CO Concentration**	Health Consequences***	
		Excess Deaths	Disabled Person-Hours
2000	1.3	-	-
	1.5	-	-
	1.7	-	52
4000	1.3	-	14
	1.5	-	688
	1.7	.18	2738
6000	1.3	-	1572
	1.5	.33	6397
	1.7	1.47	12777
8000	1.3	.23	10912
	1.5	1.89	20302
	1.7	4.74	30285
10000	1.3	1.68	30064
	1.5	5.49	40954
	1.7	10.16	53049

*annual geometric mean of the daily maximum 8-hour average concentration, expressed in ug/m^3.

**standard geometric deviation

***per million total population per year.

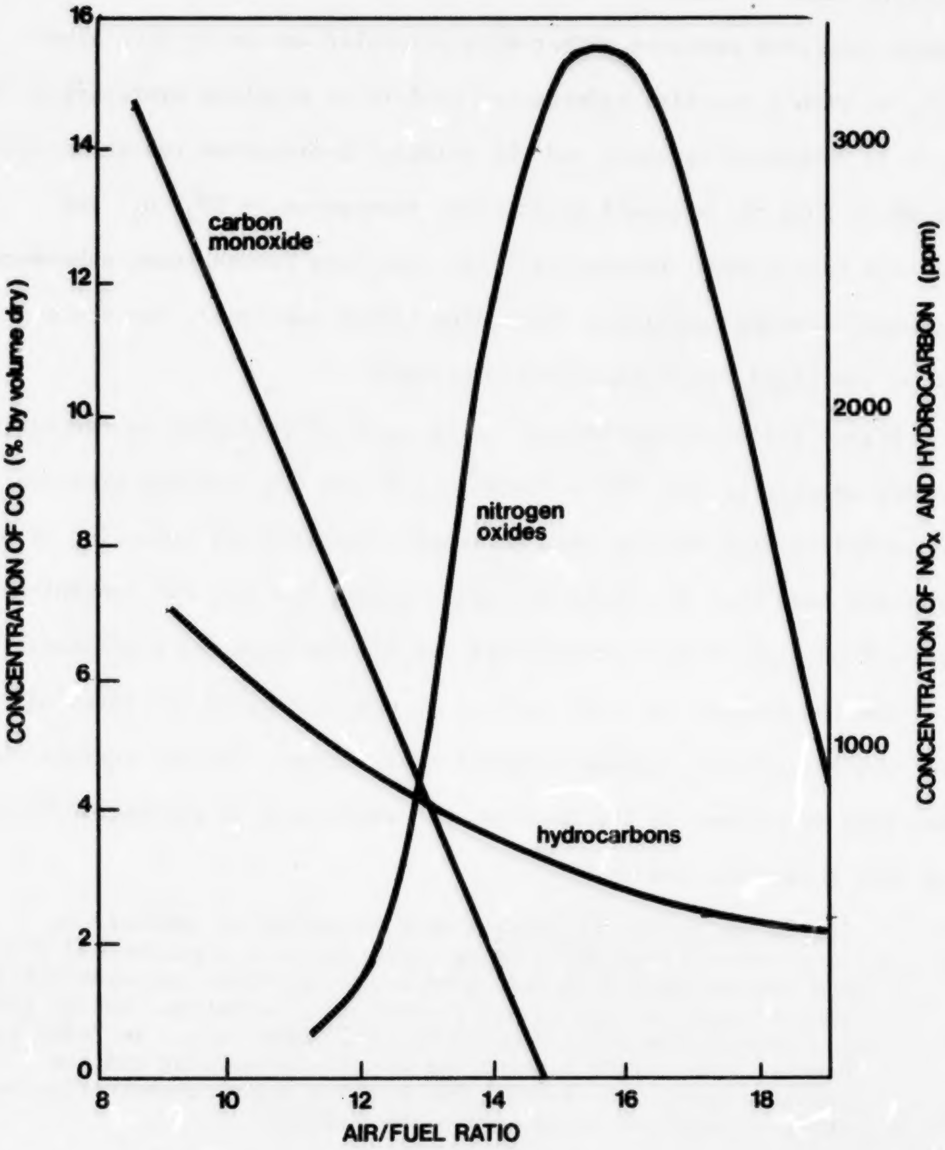
Source: (4, pp. 3-18)

combustion chamber make it difficult to eliminate this problem entirely. There are other, relatively minor, sources of automotive hydrocarbons, including:

- crankcase emissions - Gases escaping from the crankcase (produced by "blowby" and evaporation of the oil) contain some hydrocarbons. These emissions now are recycled through the carburator, but for pre-1968 vehicles were vented into the air.
- hot-soak emissions - Each time a warmed up vehicle is turned off, a certain amount of gasoline remains in the carburetor. This gasoline evaporates and escapes through the air intake as a hydrocarbon rich vapor.
- "diurnal" emissions - Through normal evaporation, gases continually escape from the fuel tank. Although valves can be devised to restrict these emissions, complete elimination is impossible because of the need to allow for expansion and contraction with changes in temperature.

In contrast with CO and HC, nitrogen oxides are the by-products of efficient and well-regulated combustion processes, and for this reason are more common in stationary source emissions than either of the other two. This happens because NO_X is formed at the high temperatures which occur when combustion is complete. About 32% of all NO_X emissions come from automobiles, with another 15% from other mobile sources. Ironically, many of the measures which tend to reduce HC and CO formulation have the opposite effect on NO_X. For the case of automobiles, this is illustrated in Figure H-2. All other things being equal, an attempt to decrease HC and CO by increasing the air/fuel ratio beyond 12 (in this example) will boost NO_X output dramatically.

Nitrogen oxides and hydrocarbons react synergistically in the atmosphere to form photochemical smog, which is a descriptive term for a mixture of nitric oxide (NO), nitrogen oxide (NO_2), reactive hydrocarbons, oxidized hydrocarbons, and ozone (O_3). After emission, the NO (which makes up approximately 85% of the NO_X emitted by autos) rapidly oxidizes



Source (4)

FIGURE H-2

Relationship of Combustion Products to Air-fuel Mixture to NO_2 (the "brownish" component of smog); under intense solar radiation, this, in turn, is reconverted to NO, leaving a free oxygen atom. This oxygen atom then combines either with molecular oxygen to form ozone (O_3^+), or with a reactive hydrocarbon to form an oxidized hydrocarbon. The cycle is completed as ozone and the oxidized hydrocarbon recombine with the NO to form the original constituent substances -- NO_2, O_2, and reactive hydrocarbon. Eventually, side reactions remove these substances, but under certain conditions (including bright sunlight), the cycle may be sustained for a considerable period.[1]

Figure H-3 shows the average daily cycle of pollutant concentrations for Los Angeles in the 1950's. Lingering HC and NO_X from the previous day, combined with morning peak emissions, initiate the formation of ozone and more NO_2. The cycle continues during the day, but concentrations fall off as some of the contaminants are removed from the atmosphere.

The Los Angeles data are typical of the smog cycle in cities all over the country, if perhaps somewhat more extreme. The key factors which make smog so extreme in Los Angeles, and which must be present anywhere for smog formation, are:

- Stagnation of the air mass - Smog formation is unlikely to occur when strong winds bring clean air into a region and disperse the contaminants downwind. However, local winds not associated with a major pattern do not prevent smog formation, and in fact, can cause a heavy build-up in a "dead" area (e.g., an "eddy"). Diurnal local winds blowing one-way in the morning and the opposite way in the evening can build a heavy concentration and shift it back and forth across the region.
- Depth of the mixing layer - Under good atmospheric conditions, air near the surface is warmed by sunshine, rises into the upper

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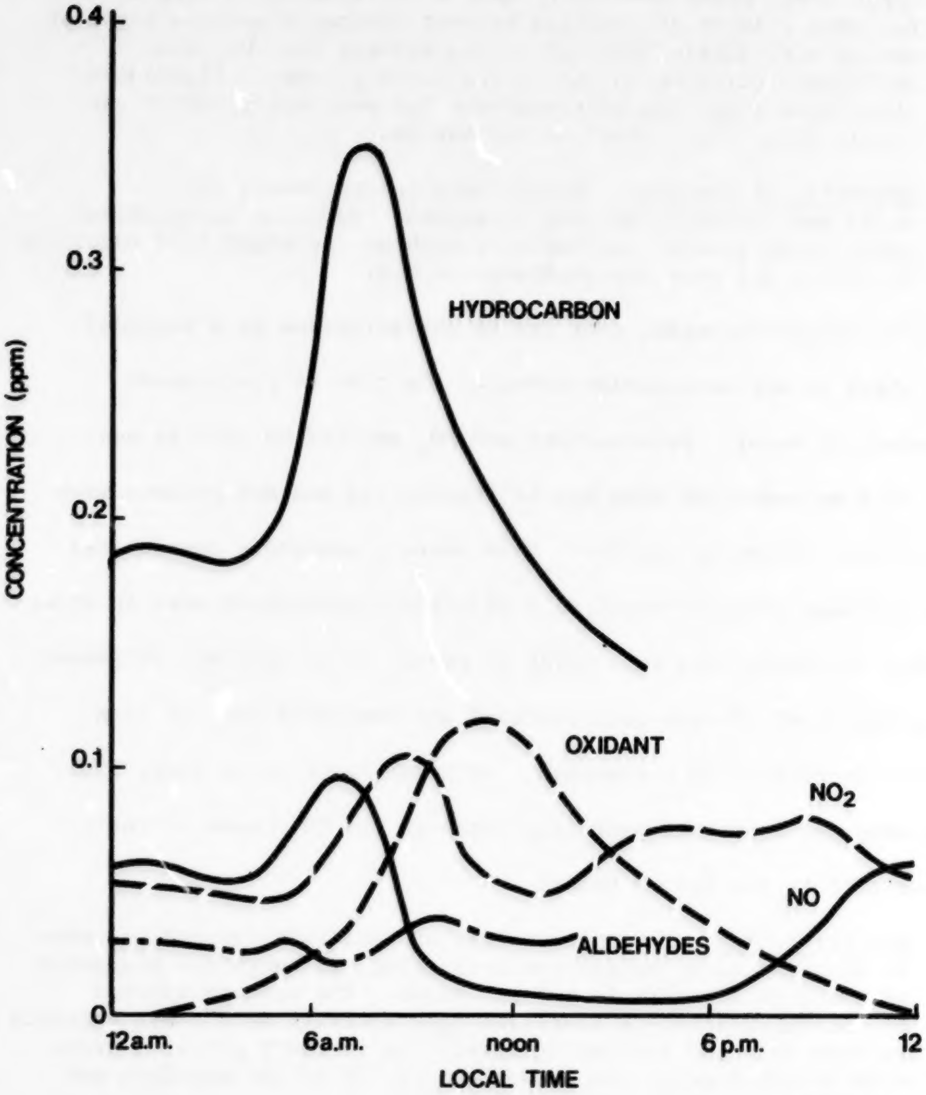
[1] This summary description of smog formation is adapted from several sources, including Williamson, Fundamentals of Air Pollution (4). Even now, the process is not completely understood, and other experts may take a slightly different view.



Source (4)

FIGURE H-3

Evolution of Photochemical Smog as Indicated by Average Levels of Pollution in Downtown Los Angeles layers, and is replaced by clean, cooler air from above. Upper level winds then carry away any atmospheric contaminants. But when a layer of cool air becomes trapped beneath a layer of warmer air, little "mixing" occurs between the two, and pollutants build up in the cooler surface layer. Figure H-4 shows four condition of topography and meteorology which can result in an "inversion" of air masses.

- Intensity of sunshine - Bright sunshine increases the speed and intensity of smog formation. Sunshine is brightest under conditions of low humidity such as one might find regularly in cities all over the southwestern U.S.

Unlike carbon monoxide, smog can be characterized as a regional problem which is not necessarily worst at the time or place where heavy emissions occur. Hydrocarbons and NO_X emitted by cars in one section of a metropolitan area may be transported and may produce smog in an entirely different section. This poses a seemingly paradoxical need to restrain vehicle travel in a relatively unpolluted area in order to protect the health and well being of people in an entirely different area. A number of adverse environmental and health effects of smog have been identified and documented, although there is no clear link between smog and increased mortality rates as for CO. Some of the principal effects are listed below:

- Eye irritation - The hydrocarbons and oxidants (excepting ozone) in smog may cause severe eye irritation, although the mechanism by which this occurs is not yet known. The primary symptom of this irritation is increased tear activity as the eye attempts to wash away the irritating agent. In severely polluted areas, such as Los Angeles and Denver, up to 75% of the populace may experience some discomfort.

- Respiratory effects - Ozone may cause irritation and decreased efficiency of the respiratory tract even at very low concentrations (> .1 ppm), and exposure for an hour or more at 1 ppm can lead to chest discomfort, cough, headache, aggravation of asthma, and aggravation of heart and lung disease in elderly patients. Maximum concentrations of photochemical oxidant, of which ozone is the primary component, may exceed .15 ppm in chronically polluted cities. There is no evidence of chronic respiratory disease in humans or of any irreversible change in the respiratory tract resulting from long-term exposure.

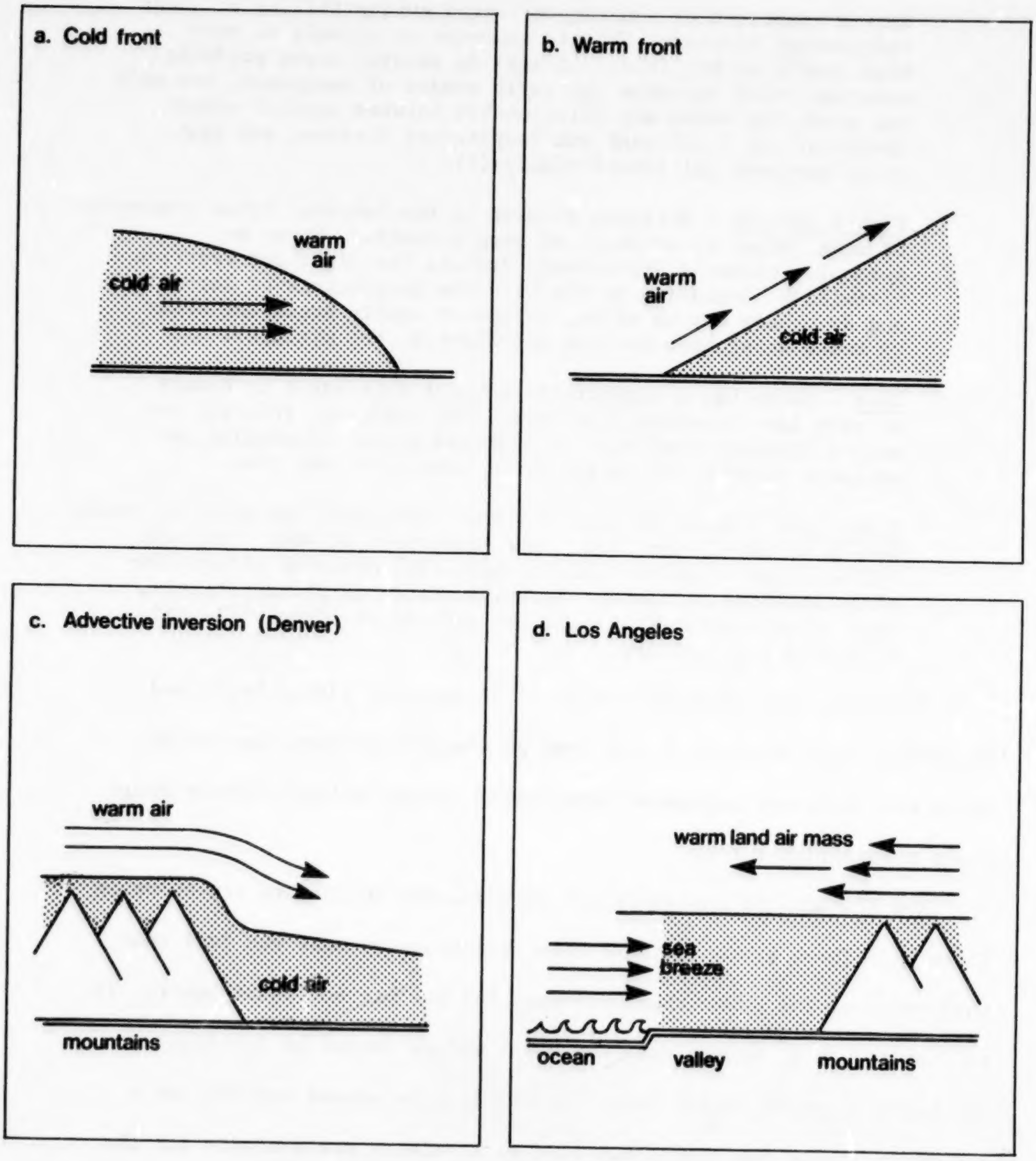

a. Cold front
warm air
cold air
b. Warm front
warm air
cold air
c. Advective inversion (Denver)
warm air
cold air
mountains
d. Los Angeles
warm land air mass
sea breeze
ocean
valley
mountains

FIGURE H-4

Conditions for the Formation of an Inversion

NO_2 is suspected of causing increased susceptibility to lower respiratory diseases. Chronic exposure of animals to very high levels of NO_2 (e.g., .5 ppm) in several weeks produces symptoms which resemble the early stages of emphysema, but only one study has shown any relationship between typical urban levels of NO_2 (~,05 max) and respiratory disease, and that study has been criticized widely (5).

Visual effects - Nitrogen dioxide is the familiar brown component of smog. Other by-products of smog formation, known as aerosols (airborne particles), diffuse the light and restrict visibility. Depending on the relative proportions of aerosols and NO_2, smog may be white, yellow or nearly brown (or clear if these substances are not prevalent in the mixture).

Odor - Ozone has a characteristic odor noticeable to humans at very low concentrations (e.g., .02 ppm), but this has not been a frequent complaint in polluted areas. Adaptation apparently reduces the intensity of sensation over time.

Plant life - Toxic effects on plants have been recorded for ozone levels of .05-.1 ppm, and other components of smog - NO_2 and hydrocarbons - can be toxic as well. The observed effects include spotting of leaves, decreased rates of photosynthesis, loss of vegetation (i.e., leaves shrivel and drop off), and a drop in productivity.

The unpleasant short-term effects of smog are widely known and reasonably well documented. For some of the effects described above, Table H-3 shows the estimated "threshold" levels at which humans would begin to experience them.

The EPA ambient standards for smog-related pollutants are shown in Table H-1. These standards have been challenged by many who feel that they were set far lower than necessary for the protection of health. In particular, it is argued that the NO_2 standard cannot be justified on the basis of known health data. But NO_2 must be viewed not only as a pollutant in its own right, but also as a primary prerequisite for the production of smog. In a recent study of the EPA standards, the National Academy of Sciences found insufficient justification for raising any of the standards (i.e. allowing greater emissions) and suggested that perhaps the NO_x standard, in fact, should be made more stringent (6).

TABLE H-3

Threshold Exposure Levels for Adverse Health Effects from Smog

Adverse Health Consequences	Threshold Concentration (for one hour or more - in ug/m^3)
Aggravation of Heart and Lung Disease in Elderly Patients	400
Aggravation of Asthma	400
Eye Discomfort	260
Cough	400
Chest Discomfort	420
Headache	100

Source: (5, pp. 3-24)

QUANTIFICATION OF AIR QUALITY BENEFITS

The economic value of benefits from air pollution control has been extensively analyzed in recent years with two alternative methodologies. In the first of these, households are assumed to take account of air quality in choosing among residential sites. Given several dwellings that are identical in every way except for the quality of ambient air, households will presumably bid up the price of those with clean air. The resulting price differentials then can be used to learn something about the willingness of households to pay for clean air. Because price differentials will arise only for those air quality impacts which households can detect, property value studies are generally assumed to measure readily apparent benefits such as absence of dirt, eye irritation, and impaired visibility.

The second method for computing the value of clean air benefits requires direct estimates of pollution damage to human health, animals, vegetation, and industrial productivity. Once these damages have been ascertained, their economic cost can be estimated by computing, for example, the cost of medical care to counteract health effects, the loss of production because of pollution related absenteeism from work, the value of crops damaged by polluted air, and so forth. The benefits from pollution control are simply the elimination of costs attributable to contaminated air. These benefits are usually assumed to be distinct from those measured by property value studies, and total benefits from air quality improvements are often estimated as the sum of the two. This assumption is open to criticism, however. If households are aware of the health costs of dirty air, the price differential among properties that differ in the quality of ambient air will reflect these costs, as well as those enumerated in the discussion of property value studies. Adding health benefits to those measured by property value studies leads to double counting. Only under the uncertain assumption that households do not accurately perceive the health effect of air pollution is this addition defensible.

Further sources of uncertainty arise when the two methods of measuring air quality benefits are examined in greater detail. Consider first the property value method. Property value studies begin by estimating a hedonic price regression that relates the price of different dwellings in different neighborhoods to the characteristics of the dwelling, neighborhood attributes, and air quality. The estimated equation takes the general form

$$P_i = \rho(D_i, N_i, A_i), \qquad (1)$$

where P_i is dwelling price, D_i is dwelling characteristics, N_i is neighborhood attributes, and A_i is air quality. Each household is assumed to purchase air quality improvements as long as their cost is less than their value to the household and to stop when the price of further improvement is just equal to its value. Therefore, the extra housing cost borne by any household to live at its current level of air quality rather than the next lower level is assumed exactly equal to its willingness to pay for air quality improvements. The cost of moving from one level of quality to another, in turn, can be computed by seeing how price varies with air quality in Equation (1). Therefore, we can define

$$W_i = \frac{\partial P_i}{\partial A_i} , \qquad (2)$$

where W_i is the households' willingness to pay for cleaner air.

Willingness to pay for air quality improvements is likely to vary among households for several reasons. First, it may differ for identical households living at different levels of air pollution. For example, it is likely that households living in highly polluted areas will value a given reduction in pollution more highly than those in areas where the air is already quite clean. Likewise, households with different tastes and different incomes will place differing values on the same air quality improvement. Therefore, willingness to pay for reductions in pollution can be expressed as a function of the existing air quality, household tastes for clean air, and household income:

$$W_i = W(A_i, T_i, Y_i) \, , \qquad (3)$$

where T_i represents tastes and Y_i represents income. Once the exact nature of the relationships in (3) has been estimated, it is possible to measure the value of any change in air quality for every household affected by the change and to obtain an economic value for those air quality benefits perceived by households in making residential choices. Unfortunately, existing research has found estimated benefits to be so sensitive to the exact functional form assumed for (1) and (3) that no reliable estimates have as yet been obtained from property value studies.

Similar uncertainties afflict attempts to estimate directly the benefits of eliminating pollution related damage to health and vegetation. If the physical effects of pollution could be confidently ascertained, their economic value could be estimated without difficulty. The cost of health care, the value of production lost to pollution related absenteeism from work, and the value of damage to crops can all be computed from market prices.

However, acceptably precise estimates of the physical relationship between air quality and mortality, illness, and vegetation damage are unavailable. Field workers, epidemiologists, and economists have all sought to estimate physical damage functions for various kinds of pollution. As previously noted, the evidence is sufficient to justify a confident assertion that harmful effects do exist. However, the estimates vary sufficiently from one another so as to be wholly inadequate for quantitative measurement of the costs of pollution and the benefits from air quality improvements.

A recent survey of the state of the art for both property value studies and direct estimation of economic benefits from pollution control led Smith to conclude that "these techniques do not now offer reliable estimates of the damages associated with air pollution." (7 , pp. 3-4). Therefore, rather than trying to quantify economic costs and benefits with inadequate information, acceptance of the following suggestion by Baumol may be appropriate (8, p. 31B).

> On issues as important as those we are discussing, given the limited information at ones disposal, it is perfectly reasonable to act on the basis of a set of minimum standards of acceptability. If, say, we treat the sulphur content of the atmosphere as one of the outputs of the economic system, it is not unreasonable to select some maximal level of this pollutant that is considered satisfactory and to seek to determine a tax on the offending input or outputs capable of achieving the chosen standard. This is precisely the approach employed in the formulation of stabilization policy, where it is decided that an employment rate (sic.) exceeding W percent and a rate of inflation exceeding V percent per year are simply unacceptable and fixed and monetary measures are then designed accordingly.

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